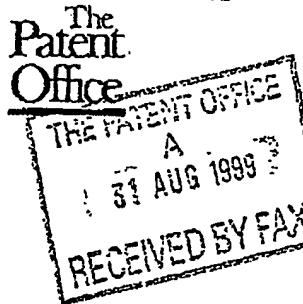


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2. Patent application number

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**9920460.4**

**31 AUG 1999**

3. Full name

each applicant (underline all surnames)

Measurement Devices Limited  
Silverburn Crescent  
Bridge of Don  
ABERDEEN  
AB23 8EW.

Patents ADP number (if you know it)

U118527001

If the applicant is a corporate body, give the country/state of its incorporation

United Kingdom

4. Title of the invention

Survey Apparatus and Method

5. Name of your agent (if you have one)

Murgitroyd & Company

"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

373 Scotland Street  
Glasgow  
G5 8QA

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Country      Priority application number  
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Signature *Murgitroyd & Co* Date  
Murgitroyd & Company 31 August 1999

12. Name and daytime telephone number of person to contact in the United Kingdom Jamie Allan 01224 706 616

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1 "Survey Apparatus and Method"

2

3 The present invention relates to survey apparatus and  
4 method and particularly, but not exclusively, to a  
5 survey apparatus for, and a method of, creating a three  
6 dimensional image.

7

8 Conventional survey equipment typically measures the  
9 distance, bearing and inclination angle to a target  
10 (such as a tree, electricity pylon or the like) or a  
11 target area, with reference to the position of a user.  
12 While this information is useful, it would be  
13 advantageous to create a three-dimensional (3D) image  
14 of the target and/or target area.

15

16 In addition, conventional sighting devices which are  
17 used to select a target to be surveyed often result in  
18 false surveys being made as the target is often not  
19 correctly identified.

20

21 There are a number of conventional techniques which are  
22 capable of generating a three-dimensional (3D) image  
23 from photographs. One such technique is  
24 stereophotography (SP). SP uses two simultaneous  
25 images taken by two cameras positioned at fixed points.

1 The two fixed points are precisely spaced apart along a  
2 baseline distance.

3

4 However, this conventional technique has a number of  
5 associated disadvantages. Firstly, the pictures are  
6 not direct to digital, which creates difficulties in  
7 manipulating the images after they have been taken.  
8 The images typically require to be ortho-corrected and  
9 the method itself is generally slow and can be  
10 expensive due to the precision cameras required.

11

12 According to a first aspect of the present invention  
13 there is provided survey apparatus comprising an  
14 imaging device, a range finder, and a processor capable  
15 of receiving and processing image and range signals to  
16 construct a three-dimensional image from said signals.

17

18 According to a second aspect of the present invention  
19 there is provided a method of generating a three-  
20 dimensional image of a target area, the method  
21 comprising the steps of providing an imaging device,  
22 providing a range finder, operating the imaging device  
23 to provide an image of the target area, and  
24 subsequently measuring the distance to each of a  
25 plurality of points by scanning the range finder at  
26 preset intervals relating to the points.

27

28 The imaging device is preferably a camera, typically a  
29 digital video camera, and preferably a charge-coupled  
30 device (CCD) video camera. Alternatively, the camera  
31 may comprise a digital camera. The camera is  
32 preferably capable of zoom functions. This allows  
33 targets which may be some distance from the apparatus  
34 to be viewed more accurately and/or remotely.

35

36 The apparatus typically includes a display device to

1 allow a user to view a target area using the imaging  
2 device. The display device typically comprises a VGA  
3 eyepiece monitor, such as a liquid-crystal display  
4 (LCD) or flat panel display. The display device may  
5 alternatively comprise a VGA monitor. This offers the  
6 advantage that an image of the target may be viewed by  
7 the user to ensure that the correct target has been  
8 selected. Also, the survey apparatus may be operated  
9 remotely using the camera to view the target area.

10

11 The apparatus preferably includes a pan and tilt unit  
12 for panning and tilting of the range finder and/or  
13 camera. The pan and tilt unit typically comprises a  
14 first motor for panning of the range finder and/or  
15 camera, and a second motor for tilting of the range  
16 finder and/or camera. The pan and tilt unit typically  
17 includes first and second digital encoders for  
18 measuring the angles of pan and tilt respectively. The  
19 first and second motors are typically controlled by the  
20 processor. The outputs of the first and second  
21 encoders is typically fed to the processor. This  
22 provides a feedback loop wherein the motors are  
23 operated to pan and tilt the range finder and/or camera  
24 through the generated horizontal and vertical angles.  
25 The encoders may then be used to check the angles to  
26 ensure that the range finder and/or camera were panned  
27 and tilted through the correct angles.

28

29 The image is preferably digitised, wherein the image  
30 comprises a plurality of pixels. Optionally, the image  
31 may be a captured image. The target is typically  
32 selected by selecting a plurality of pixels around the  
33 target, using, for example, a mouse pointer. This  
34 produces x and y coordinates for the target pixels and  
35 defines a target area eg a building or a part thereof.  
36

1      Typically, the range finder is preferably a laser range  
2      finder. Preferably, the laser range finder is bore-  
3      sighted with the camera. This, in conjunction with the  
4      eyepiece monitor used to identify the target area,  
5      offers the advantage that the user can be sure that the  
6      target area he has selected will be captured by the  
7      camera. In addition, any subsequent calculations made  
8      by the processor do not require an offset between the  
9      camera and the range finder to be considered.

10

11     Preferably, the survey apparatus includes a compass and  
12     an inclinometer and/or gyroscope. These allow the  
13     bearing and angle of inclination to the target to be  
14     measured. These are preferably digitised to provide  
15     data to the processor.

16

17     Optionally, the survey apparatus further includes a  
18     position fixing system for identifying the geographical  
19     position of the apparatus. The position fixing system  
20     is preferably a Global Positioning System (GPS) which  
21     typically includes a Differential Global Positioning  
22     System (DGPS). This provides the advantage that the  
23     approximate position of the user can be recorded (and  
24     thus the position of the target using the measurements  
25     from the range finder and compass, where used.

26     Preferably, the GPS/DGPS facilitates the time of the  
27     survey to be recorded.

28

29     The survey apparatus is typically mounted on a mounting  
30     device. The mounting device typically comprises  
31     headgear which may be worn on the head of a user. The  
32     headgear typically comprises a hard-hat type helmet.  
33     Alternatively, the survey apparatus may be located  
34     within a housing. The housing is typically a hand-held  
35     device. Optionally, the mounting device may be a  
36     tripod stand or a platform which forms part of an

1 elevation system, wherein the survey apparatus is  
2 elevated to allow larger areas to be surveyed.

3

4 Optionally, the apparatus may be operated by remote  
5 control.

6

7 The compass is preferably a digital fluxgate compass.

8

9 The survey apparatus is typically controlled by an  
10 input device. The input device is typically used to  
11 activate the surveying apparatus, and may be a  
12 keyboard, keypad, penpad or the like. Typically, the  
13 input device facilitates operation of a particular  
14 function of the apparatus. The input device is  
15 typically interfaced to the processor via a standard  
16 keyboard input.

17

18 The GPS/DGPS is preferably integrally moulded within  
19 the helmet.

20 The method typically includes the additional step of  
21 selecting the target area to be surveyed using the  
22 imaging device.

23

24 The method typically includes any one, some or all of  
25 the further steps of

26 obtaining a focal length of the camera;  
27 obtaining a field of view of the camera;  
28 calculating the principal distance of the camera;  
29 obtaining the horizontal offset and vertical  
30 offset between an axis of the camera and an axis of the  
31 laser;  
32 calculating the horizontal and vertical offsets in  
33 terms of pixels;  
34 calculating the difference between the horizontal  
35 and vertical offsets in terms of pixel and the x and y  
36 coordinates of the target pixel; and

1 calculating the horizontal and vertical angles.  
2  
3 Optionally, the method typically includes one, some or  
4 all of the further steps of  
5 instructing the pan and tilt unit to pan and tilt  
6 the range finder and/or camera through the vertical and  
7 horizontal angles;  
8 measuring the horizontal and vertical angles using  
9 the encoders;  
10 verifying that the angles through which the range  
11 finder and/or camera are moved is correct;  
12 obtaining horizontal and/or vertical correction  
13 angles by subtracting the measured horizontal and  
14 vertical angles from the calculated horizontal and  
15 vertical angles;  
16 adjusting the pan and tilt of the range finder  
17 and/or camera if necessary; and  
18 activating the range finder to obtain the range to  
19 the target.  
20  
21 Preferably, the method includes the additional step of  
22 correlating the position of the pixels in the digital  
23 picture with the measured distance to each pixel. This  
24 generates a set of x, y and z co-ordinates for all of  
25 the pixel points which may be used to generate a three  
26 dimensional image of the target area.  
27  
28 Embodiments of the present invention shall now be  
29 described, by way of example only, with reference to  
30 the accompanying drawings in which:-  
31 Fig. 1 is a schematic representation of an image  
32 capture and laser transmitter and receiver unit in  
33 accordance with, and for use with, the present  
34 invention;  
35 Fig. 2 shows schematically a first embodiment of  
36 survey apparatus;

1 Fig. 3 shows an exploded view of the survey  
2 apparatus of Fig. 2 in more detail;  
3 Fig. 4 shows a simplified schematic illustration  
4 of a digital encoder;  
5 Fig. 5 schematically shows the survey apparatus of  
6 Figs 2 and 3 in use;  
7 Fig. 6 is a schematic representation of the  
8 display produced on a computer screen of a freeze  
9 frame image produced by a digital camera;  
10 Fig. 7 is a simplified schematic diagram of inside  
11 a digital camera;  
12 Fig. 8 is a simplified diagram illustrating how a  
13 principal distance (PD) may be calculated;  
14 Fig. 9 is a simplified diagram illustrating the  
15 offset between the laser and the camera in use;  
16 Fig. 10 is a schematic representation illustrating  
17 a horizontal offset  $H_{offset}$  outwith the camera;  
18 Fig. 11 is a schematic representation illustrating  
19 a horizontal distance  $l_x$  in terms of pixels,  
20 corresponding to  $H_{offset}$ , within the camera;  
21 Fig. 12 is a simplified diagram of a freeze frame  
22 image showing an object;  
23 Fig. 13 is a schematic representation illustrating  
24 the relationship between a horizontal distance  $d_x$ ,  
25 a principal distance PD and an angle  $\theta$ ;  
26 Fig. 14 is a simplified diagram illustrating the  
27 principle of calculating pixel x and y co-  
28 ordinates from horizontal and vertical angles of  
29 and range to the pixel;  
30 Fig. 15 is a simplified diagram illustrating the  
31 relationship between horizontal and vertical  
32 angles of and range to the pixel and three  
33 dimensional co-ordinates of the pixel;  
34 Fig. 16 is a print of the triangular framework  
35 used to recreate a 3D image of a bitmap  
36 photograph;

1 Fig. 17 shows a print of a 3D image which used a  
2 bitmap photograph superimposed on the framework of  
3 Fig. 16;  
4 Fig. 18 is a representation of an alternative  
5 mounting device for the survey apparatus according  
6 to a first aspect of the present invention;  
7 Fig. 19a is a schematic representation of a  
8 vehicle provided with an elevating arm and survey  
9 apparatus showing the position of the apparatus  
10 when the vehicle is moving;  
11 Fig. 19b is a schematic representation of the  
12 vehicle of Fig. 19a with the apparatus deployed on  
13 the arm;  
14 Fig. 19c is a schematic representation of the  
15 vehicle of Figs 19a and 19b on a slope with the  
16 apparatus deployed on the arm;  
17 Figs 20a and 20b are respective rear and side  
18 views of the survey apparatus deployed on the arm;  
19 Figs 21a and 21b are respective side and plan  
20 elevations of the vehicle of Figs 15a to 15c  
21 illustrating the survey apparatus being used to  
22 profile the ground in front of the vehicle;  
23 Fig. 22 is a schematic view of a second embodiment  
24 of a mounting device;  
25 Figs 23 to 27 show a hand-held housing for the  
26 survey apparatus according to a first aspect of  
27 the present invention; and  
28 Figs 28 to 30 show the hand-held housing of Figs  
29 23 to 27 in use.  
30  
31 Referring to the drawings, Fig. 1 shows a schematic  
32 representation of an image capture and laser  
33 transmitter and receiver unit 10 which forms part of  
34 the survey apparatus in accordance with a first aspect  
35 of the present invention. Unit 10 includes a laser 12  
36 (which typically forms part of a laser range finder),

1 whereby the laser 12 generates a beam of laser light  
2 14. The laser 12 is typically an invisible, eyesafe,  
3 gallium arsenide (GaAs) diode laser which emits a beam  
4 typically in the infra-red (ie invisible) spectrum.  
5 The laser 12 is typically externally triggered and is  
6 typically capable of measuring distances up to, or in  
7 excess of, 1000 metres (1 km).

8

9 The beam 14 is reflected by a part-silvered prism 16 in  
10 a first direction substantially perpendicular to the  
11 direction of the initial beam 14, thereby creating a  
12 transmit beam 18. The transmit beam 18 enters a series  
13 of transmitter optics 20 which collimates the transmit  
14 beam 18 into a target beam 22. The target beam 22 is  
15 reflected by a target (schematically shown in Fig. 1 as  
16 24) and is returned as a reflected beam 26. The  
17 reflected beam 26 is collected by a series of receiver  
18 optics 28 and directs it to a laser light detector 30.  
19 The axes of the transmit and receiver optics 20, 28 are  
20 calibrated to be coincident at infinity.

21

22 Signals from the detector 30 are sent to a processor  
23 (not shown in Fig. 1), the processor typically forming  
24 part of a computer. The processor calculates the  
25 distance from the unit 10 to the target 24 using a  
26 time-of-flight principle. Thus, by dividing the time  
27 taken for the light to reach the target 24 and be  
28 reflected back to the detector 30 by two, the distance  
29 to the target 24 may be calculated.

30

31 A digital video camera 32 is bore-sighted with the  
32 laser 12 (using the part-silvered prism 16). The  
33 camera 32 is preferably a complementary metal-oxide  
34 silicon (CMOS) camera which is formed on a silicon  
35 chip. The chip generally includes all the necessary  
36 drive circuitry for the camera. It should be noted

10

1 that the camera 32 need not be bore-sighted with the  
2 laser 12. Where the camera 32 is not bore-sighted with  
3 the laser 12, the axis of the laser 12 will be offset  
4 from the axis of the camera 32 in the x and/or y  
5 directions. The offset between these axes can be  
6 calculated and the survey apparatus calibrated (eg  
7 using software) to take account of these offsets.  
8 However, where the camera 32 and the laser 12 are bore-  
9 sighted (as in Fig. 1) there is no requirement to take  
10 account of the offset in any subsequent calculations.  
11 The camera 32 is advantageously capable of zoom  
12 functions as this facilitates selection of targets at  
13 distances up to, or in excess of, 1 km.

14  
15 The transmit optics 20 serve a dual purpose and act as  
16 a lens for the camera 32. Thus, light which enters the  
17 transmit optics 20 is collimated and directed to the  
18 camera 32 (shown schematically at 34) thereby producing  
19 an image of the target 24 at the camera 32. The image  
20 which the camera 32 receives is digitised and sent to a  
21 processor (not shown in Fig. 1). It will be  
22 appreciated that a separate lens may be provided for  
23 the camera 32 if required.

24  
25 Referring now to Figs 2 and 3, Fig. 2 shows  
26 schematically a first embodiment of survey apparatus  
27 100 mounted for movement in x and y directions (ie pan  
28 and tilt), and Fig. 3 shows an exploded view of the  
29 survey apparatus 100 of Fig. 2 in more detail.

30  
31 Referring firstly to Fig. 2, the image capture and  
32 laser transmitter and receiver unit 10 (Fig. 1) is  
33 typically mounted within a casing 50. The casing 50 is  
34 typically mounted to a U-shaped yoke 52, yoke 52 being  
35 coupled to a vertical shaft 54. Shaft 54 is rotatably  
36 mounted to facilitate rotational movement (indicated by

11

1 arrow 56 in Fig. 2) of the casing 50 in a horizontal  
2 plane (indicated by axis 58) which is the x-direction  
3 (ie pan). The rotational movement of the shaft 54 (and  
4 thus the yoke 52 and casing 50) is controlled by a  
5 motor 60 coupled to the shaft 54, typically via a  
6 gearbox (not shown in Fig. 2). The operation of the  
7 motor 60 is controlled by the computer.

8  
9 The angle of rotation of the casing 50 in the  
10 horizontal plane (ie panning of the unit 10 in the x-  
11 direction) is measured accurately by a first digital  
12 encoder 62, attached to the shaft 54 in a known manner,  
13 which measures the angular displacement of the casing  
14 50 (and thus the transmit laser beam 22) in the x-  
15 direction.

16  
17 Similarly, the yoke 52 allows the casing 50 (and thus  
18 the transmit laser beam 22) to be displaced in the y-  
19 direction as indicated by arrow 64. The casing 50 is  
20 mounted to the yoke 52 via a horizontal shaft 66.  
21 Shaft 66 is rotatably mounted to facilitate rotational  
22 movement (indicated by arrow 64 in Fig. 2) of the  
23 casing 50 in a vertical plane (indicated by axis 68)  
24 which is the y-direction (ie tilt). The rotational  
25 movement of the shaft 66 (and thus the yoke 52 and  
26 casing 50) is controlled by a motor 68 coupled to the  
27 shaft 56, typically via a gearbox (not shown in Fig.  
28 2). The operation of the motor 66 is controlled by the  
29 computer.

30  
31 The angle of rotation of the casing 50 in the vertical  
32 plane (ie tilting of the unit 10 in the y-direction) is  
33 measured accurately by a second digital encoder 70,  
34 attached to shaft 66 in a known manner, which measures  
35 the angular displacement of the casing 50 (and thus the  
36 transmit laser beam 22) in the y-direction. Thus, the

12

1       motors 60, 68 provide for panning and tilting of the  
2       casing 50.  
3  
4       The output of the first and second encoders 62, 70 is  
5       electrically coupled to the computer to provide a  
6       feedback loop. The feedback loop is required because  
7       the motors 60, 68 are typically coupled to the shafts  
8       54, 66 via respective gearboxes and are thus not in  
9       direct contact with the shafts 54, 66. This makes the  
10      movement of the casing 50 which is effected by  
11      operation of the motors 60, 68 less accurate. However,  
12      as the encoders 62, 70 are coupled directly to their  
13      respective shafts 54, 66 then the panning and tilting  
14      of the casing in the x- and y-directions can be  
15      measured more accurately, as will be described.  
16  
17      The embodiment of the image capture and laser  
18      transmitter and receiver unit 10 shown in Fig. 2 is  
19      slightly different from that illustrated in Fig. 1.  
20      The camera 32 within unit 10 is not bore-sighted with  
21      the laser 12, and thus casing 50 is provided with a  
22      camera lens 72, a laser transmitter lens 74 and a laser  
23      receiver lens 76. It should be noted that the laser  
24      transmitter lens 74 and the camera lens 72 may be  
25      integrated into a single lens as illustrated in Fig. 1.  
26      Ideally, the camera lens 72, laser transmitter lens 74  
27      and laser receiver lens 76 would be co-axial. This  
28      could be achieved in practice by mechanically adjusting  
29      the lenses 72, 74, 76 to make them co-axial. However,  
30      this is a time consuming process and the offsets  
31      between the lenses can be calculated and the survey  
32      apparatus can be calibrated to take these offsets into  
33      account, as will be described. This calibration is  
34      generally simpler and quicker than mechanically  
35      aligning the lenses 72, 74, 76.  
36

1 Referring to Fig. 3, there is shown in more detail the  
2 apparatus of Fig. 2. It should be noted that the  
3 casing 50 which houses the image capture and laser  
4 transmitter and receiver unit 10 is not provided with a  
5 separate camera lens 72 (as in Fig. 2). It should also  
6 be noted that the casing 50 in Fig. 3 is mounted to  
7 facilitate rotational movement in the x-direction  
8 (pan), but can be manually tilted in the y-direction  
9 (tilt) or can be adapted to the configuration shown in  
10 Fig. 2 for motorised pan and tilt.

11  
12 As can be seen more clearly in Fig. 3, the casing 50 is  
13 mounted to the U-shaped yoke 52. The yoke 52 is  
14 coupled to the shaft 54 using any conventional means  
15 such as screws 80. The shaft 54 is driven by the  
16 stepper motor 60 via a worm/wheel drive gearbox 82.  
17 The digital encoder 62 is provided underneath a plate  
18 84 through which the shaft 54 passes and to which the  
19 gearbox/motor assembly is attached. Plate 84 also  
20 includes a rotary gear assembly 86 which is driven by  
21 the motor 60 via the worm gearbox 82 to facilitate  
22 rotational movement of the shaft 54.

23  
24 The motor, gearbox and shaft assembly is mounted within  
25 an aluminium casing 86, the casing 86 also having a  
26 rack 88 mounted therein. The rack 88 contains the  
27 necessary electronic circuitry for driving and  
28 controlling the operation of the survey apparatus, and  
29 includes a stepper motor driver board 90, a laser  
30 control board 92 and an interface board 94.

31  
32 The first and second digital encoders 62, 70 may be of  
33 any conventional type, such as Moir Fringe, barcode or  
34 mask. Moir fringe type encoders are typically used as  
35 they are generally more accurate. Fig. 4 shows a  
36 simplified schematic illustration of a digital encoder,

1 generally designated 110. Encoder 110 typically  
2 comprises a casing 112 in which a disc 114 is rotatably  
3 mounted. The disc 114 is provided with a pattern and  
4 is typically at least partially translucent. The type  
5 of pattern defined on the disc 114 determines the type  
6 of encoder.

7  
8 A light emitting diode (LED) 116 is suspended above the  
9 disc 114 and emits a light beam (typically collimated  
10 by a lens (not shown) which shines through the disc  
11 114. The light emitted by the LED 116 is detected by a  
12 detector, typically a cell array 118. As the disc 114  
13 rotates (in conjunction with the shaft to which it is  
14 coupled) a number of electrical outputs are generated  
15 per revolution of the disc 114 by the cell array 118  
16 which detects the light passing through the disc 114  
17 from the LED 116. These types of encoders usually have  
18 two output channels (only one shown in Fig. 4) and the  
19 phase relationship between the two signals can be used  
20 to determine the direction of rotation of the disc 114.

21  
22 The encoder 110 produces a pulse output per unit of  
23 revolution. Thus, as the disc 114 rotates, the pattern  
24 on the disc 114 causes electrical pulses to be  
25 generated by the cell array 118 in response to the  
26 pattern on the disc 114. These pulses can be counted  
27 and, given that one pulse is proportional to a certain  
28 degree of rotation, the angular rotation of the disc  
29 114 and thus the shaft 54 can be calculated.

30  
31 In use, the unit 10 is typically externally triggered  
32 by an input device such as a push button, keyboard,  
33 penpad or the like. When the apparatus is triggered,  
34 the camera 32 captures a digitised image of the target  
35 area. The digitised image is made up of a plurality  
36 of pixels, the exact number of which is dependent upon

1 the size of the image produced by the camera. Each  
2 pixel has an associated x and y co-ordinate which  
3 relate to individual positions in the target area. The  
4 processor is then used to sequentially scan the laser  
5 12 (by moving the part-silvered prism 16 accordingly,  
6 or by using the motors 60, 68 in the Fig. 5 embodiment)  
7 to measure the distance (range) to each successive  
8 point in the target area given by the x and y co-  
9 ordinates of the digitised image. This can then be  
10 used to create three-dimensional co-ordinates (ie x, y  
11 and z) to allow a three-dimensional image of the target  
12 area to be produced, as will be described.

13  
14 Fig. 5 shows the survey apparatus 100 (schematically  
15 represented in Fig. 5 but shown more clearly in Figs 2  
16 and 3) in use. The apparatus 100 is controlled and  
17 operated using software installed on the computer  
18 (shown schematically at 120) via a cable 122, telemetry  
19 system or other remote or hardwired control. An image  
20 of the target is displayed on the computer screen using  
21 the camera 32 (Fig. 1) and is schematically shown as  
22 image 124 in Fig. 5. When the image 124 of the target  
23 area of interest is viewed on the screen, the user of  
24 the apparatus 100 instructs the camera 32 (included as  
25 part of the apparatus 100) to take a freeze frame image  
26 of the target area. The freeze frame image 124 is a  
27 digital image made up of a plurality of pixels and Fig.  
28 6 is a schematic representation of the display produced  
29 on the computer screen of the freeze frame image 124.  
30 The image 124 is typically divided into an array of  
31 pixels, with the image containing, for example, 200 by  
32 200 pixels in the array.

33  
34 Each pixel within the array has an x and y co-ordinate  
35 associated with it using, for example, the centre C of  
36 the picture as a reference point. Thus, each pixel

1 within the digital image can be individually addressed  
2 using these x and y co-ordinates.

3

4 The individual addresses for each pixel allow the user  
5 to select a particular object (for example a tree 126)  
6 within the digital image 124. The tree 126 can be  
7 selected using a mouse pointer for example, where the  
8 mouse pointer is moved around the pixels of the digital  
9 image by movement of a conventional mouse provided with  
10 the computer in a known manner. The x and y co-  
11 ordinates of each pixel may be displayed on the screen  
12 as the mouse pointer is moved around the image.

13 Clicking the mouse button with the pointer on the tree  
14 126 selects a particular pixel 128 within the array  
15 which is identified by its x and y coordinates.

16

17 The computer is then used to calculate the horizontal  
18 angle  $H_A$  and the vertical angle  $V_A$  (Fig. 6). The  
19 horizontal angle  $H_A$  and the vertical angle  $V_A$  are the  
20 relative angles between the centre point C of the image  
21 and the pixel 128, as schematically shown in Fig. 6.

22

23 The methodology for calculating the horizontal angle  $H_A$   
24 and the vertical angle  $V_A$  from the pixel x, y co-  
25 ordinates is as follows. Fig. 7 is a simplified  
26 schematic diagram of inside the camera 32 which shows  
27 the camera lens 72 and a charge-coupled device (CCD)  
28 array 130. The camera 32 is typically a zoom camera  
29 which therefore has a number of focal lengths which  
30 vary as the lens 72 is moved towards and away from the  
31 CCD array 130.

32

33 Referring to Fig. 7, the angles of horizontal and  
34 vertical views, or the field of view in the horizontal  
35 and vertical direction  $\theta_x$ ,  $\theta_y$  ( $\theta_y$  not shown in Fig. 7)  
36 can be calibrated and calculated at different focal

1 lengths of the camera 32. For simplicity, it is  
2 assumed that the CCD array 130 is square, and thus the  
3 field of view in the horizontal and vertical directions  
4  $\theta_x$ ,  $\theta_y$  will be the same, and thus only the field of view  
5 in the horizontal direction  $\theta_x$  will be considered. The  
6 methodology described below considers one zoom position  
7 only.

8

9 Having calculated (or otherwise obtained eg from the  
10 specification of the camera 32) the field of view in  
11 the horizontal direction  $\theta_x$  then the principal distance  
12 PD (in pixels) can be calculated. The principal  
13 distance PD is defined as the distance from the plane  
14 of the lens 72 to the image plane (ie the plane of the  
15 CCD array 130).

16

17 Referring to Fig. 8, if the image width on the CCD  
18 array is defined as  $H_x$ , then using basic trigonometry  
19  $\tan(\theta_x/2) = H_x/(2PD)$ . Thus,

20

$$21 \quad PD = H_x/(2(\tan(\theta_x/2)))$$

22

23 If the distance between each pixel in the image 124 in  
24 a certain unit (ie millimetres) is known, then the  
25 principal distance PD can be converted into a distance  
26 in terms of pixels. For example, if the field of view  
27 in the horizontal and vertical angles  $\theta_x$ ,  $\theta_y$  is, for  
28 example  $10^\circ$ , and the image contains 200 by 200 pixels,  
29 then moving one twentieth of a degree in the x or y  
30 direction is the equivalent of moving one pixel in the  
31 x or y direction.

32

33 When initially using the apparatus 100, the camera 32  
34 is used to take a calibration freeze frame image and  
35 the laser 12 is activated to return the range R to the  
36 centre point C of the image. However, the laser axis

18

1 is typically offset from the camera axis. The  
2 horizontal and vertical offsets between the laser axis  
3 and the camera axis when the freeze frame image is  
4 taken are defined as  $H_{offset}$  and  $V_{offset}$  and are known.  
5 Knowing the range  $R$  and the horizontal and vertical  
6 offsets  $H_{offset}$ ,  $V_{offset}$  allows the offset horizontal and  
7 vertical distances  $l_x$  and  $l_y$  in terms of pixels to be  
8 calculated. Referring to Fig. 9, the centre point C of  
9 the image 124 taken by the camera 32 and the laser spot  
10 132 where the transmit laser beam 22 hits the target  
11 area is typically offset by the horizontal and vertical  
12 distances  $l_x$  and  $l_y$ .

13  
14 Fig. 10 is a schematic representation illustrating the  
15 horizontal offset  $H_{offset}$  outwith the camera 32, and Fig.  
16 11 is a schematic representation illustrating the  
17 horizontal distance  $l_x$  in terms of pixels, corresponding  
18 to  $H_{offset}$ , within the camera 32. Referring to Figs 10  
19 and 11 and using basic trigonometry,

20  
21 
$$\tan \theta = H_{offset}/R$$

22 and,

23 
$$l_x = PD(\tan \theta)$$

24 Thus,

25 
$$l_x = PD(H_{offset}/R)$$

26

27 and it follows that

28 
$$l_y = PD(V_{offset}/R)$$

29

30 If the range to a certain object within the target area  
31 (such as the tree 126 in Fig. 6) is required, then the  
32 computer must calculate the horizontal and vertical  
33 angles  $H_x$ ,  $H_y$  through which the casing 50 and thus the  
34 laser beam 22 must be moved in order to target the  
35 object.

36

1 The user selects the particular pixel (relating to the  
2 object of interest) within the image using a mouse  
3 pointer. In Fig. 12, the selected object is  
4 represented by pixel A which has coordinates  $(x, y)$ ,  
5 and the laser spot 132 has coordinates  $(l_x, l_y)$   
6 calculated (eg by the computer 120) using the previous  
7 method. The coordinates  $(x, y)$  of point A are already  
8 known (by the computer 120) using the coordinates of  
9 the pixel array of the image.

10  
11 If the horizontal distance between pixel A and the  
12 laser spot 132 is defined as  $d_x$ , and similarly the  
13 vertical distance between pixel A and the laser spot  
14 132 is defined as  $d_y$ , then

15  
16 
$$d_x = x - l_x$$
  
17 and

18 
$$d_y = y - l_y,$$

19  
20 and it follows that the horizontal and vertical angles  
21  $H_A, V_A$  can be calculated as

22  
23 
$$H_A = \text{inverse tan } (d_x/PD)$$

24  
25 and  
26 
$$V_A = \text{inverse tan } (d_y/PD).$$

27  
28 Referring back to Fig. 2, having calculated the  
29 horizontal and vertical angles  $H_A, V_A$  through which the  
30 casing 50 must be rotated to measure the range to the  
31 object A, the computer 120 instructs the motor 60 to  
32 pan through an angle of  $H_A$  and simultaneously instructs  
33 the motor 68 to tilt through an angle of  $V_A$ . Thus, the  
34 transmit laser beam 22 is directed at the object A  
35 selected by the user to determine the range to it.

36

1 However, the motors 60, 68 are not directly coupled to  
2 the shafts 54, 66 (but via respective gearboxes) and  
3 thus can have errors which results in the laser beam 22  
4 not being directed precisely at the object A. However,  
5 the encoders 62, 70 can be used to measure more  
6 precisely the angles  $H_A$  and  $V_A$  through which the casing  
7 50 was panned and tilted. If there is a difference  
8 between the measured angles  $H_A$  and  $V_A$  and the angles  
9 which were calculated as above, the computer can  
10 correct for this and can pan the casing 50 through an  
11 angle  $H_{Ac}$  which is the difference between the calculated  
12 angle  $H_A$  and the measured angle  $H_A$ , and similarly tilt  
13 the casing 50 through an angle  $V_{Ac}$  which is the  
14 difference between the calculated angle  $V_A$  and the  
15 measured angle  $V_A$ . The process can then be repeated by  
16 using the encoders 62, 70 to check that the casing 50  
17 has been panned and tilted through the angles  $H_{Ac}$  and  
18  $V_{Ac}$ . If there is a difference again, then the process  
19 can be repeated to further correct for the errors  
20 introduced. This iteration process can be continued  
21 until the output from the encoders 62, 70 corresponds  
22 to the correct angles  $H_A$  and  $V_A$ . The laser 12 is then  
23 fired to give the range to the object A.

24  
25 Referring again to Fig. 6, to obtain a three  
26 dimensional (3D) image of the tree 126, the user can  
27 select a number of pixels around the outline of the  
28 tree 126. This selection limits the number of points  
29 which are used to create a 3D image. It should be  
30 noted however, that a 3D representation of the whole  
31 image 124 can be created.

32  
33 Having selected the outline of the target (ie tree  
34 126), the software provided on the computer 120  
35 instructs the motors 60, 68 to pan and tilt the unit 10  
36 through respective horizontal and vertical angles  $H_A$ ,  $V_A$



21

1 corresponding to the pixels within the tree 126 (or the  
2 entire image 124 as required). The same iterative  
3 process as described above can be used to ensure that  
4 the laser 12 is accurately directed to each of the  
5 pixels sequentially. At each pixel, the laser 12 is  
6 activated to obtain the range R to each of the pixels  
7 within the tree 126, as previously described.

9 Once the horizontal and vertical angles  $H_A$ ,  $V_A$  and the  
10 range  $R$  of each of the pixels is known, the processor  
11 within the computer 120 can then be used to calculate  
12 the 3D co-ordinates of the pixels within the tree 126  
13 to recreate a 3D image of the tree 126.

14 Referring to Fig. 14, the central laser spot 132 has an  
15 offset  $l_x$  and  $l_y$  as described above, and also has  
16 horizontal and vertical angles  $H_o$ ,  $V_o$  and range  $R_o$ .  
17 Determination of the pixel x and y coordinates  $p_x$ ,  $p_y$ ,  
18 for the point A which has horizontal and vertical  
19 angles  $H$ ,  $V$  and range  $R$ , can be done as follows using  
20 basic trigonometry. It should be noted that the field  
21 of view in the horizontal and vertical directions  $\theta_h$ ,  
22  $\theta_v$ , the principal distance PD and the horizontal and  
23 vertical distances  $l_x$  and  $l_y$ , are either all known or can  
24 be calculated as described above.  
25

$$\begin{aligned}
 27 \quad p_x - l_x &= PD \tan(H - H_o) \\
 28 \quad &\text{and} \\
 29 \quad p_y - l_y &= PD \tan(V - V_o) .
 \end{aligned}$$

31 It thus follows that

$$\begin{aligned}
 33 \quad p_x &= l_x + PD \tan(H - H_0) \\
 34 \quad &\text{and} \\
 35 \quad p_y &= l_y + PD \tan(V - V_0) \\
 36
 \end{aligned}$$

22

1 Thereafter, the 3D coordinates x, y, z for the point A  
2 can be calculated, as will be described with reference  
3 to Fig. 15.

4

5 Using trigonometry,

6

$$\begin{aligned} 7 \quad x &= R\cos V \cos H \\ 8 \quad y &= -R\cos V \sin H \\ 9 \quad &\text{and} \\ 10 \quad z &= R \sin V \end{aligned}$$

11

12 These calculations can then be repeated for each pixel  
13 (defined by  $p_x$ ,  $p_y$ ) to give 3D coordinates for each of  
14 the pixels within the target (ie tree 126 or image  
15 124). An array of pixel co-ordinates  $p_x$ ,  $p_y$  and the  
16 corresponding 3D coordinates x, y, z can be created and  
17 the processor within the computer 120 can be used to  
18 plot the 3D coordinates using appropriate software.  
19 Appendix A shows an exemplary array of pixel co-  
20 ordinates  $p_x$ ,  $p_y$  and the corresponding 3D coordinates x,  
21 y, z of a bitmap image which can be used to generate a  
22 3D image.

23

24 Once the 3D coordinates have been plotted, the software  
25 then generates a profile of the 3D image using  
26 triangles to connect each of the 3D coordinates  
27 together, as shown in Fig. 16. Fig. 16 is a print of  
28 the triangular framework used to recreate a 3D image of  
29 a bitmap photograph. The bitmap image (ie the digital  
30 image taken by the camera 32) is then superimposed on  
31 the triangulated image to construct a 3D image of the  
32 target (ie tree 126 or image 124). Fig. 17 shows a  
33 print of a 3D image which used a bitmap photograph  
34 superimposed on the framework of Fig. 16. The 3D image  
35 of the target can typically be viewed from all angles  
36 using the software. Thus, the user can effectively

1 walk around the tree 126. However, this may require a  
2 number of photographs (ie digital bitmap images taken  
3 by the camera 32) at different angles which can then be  
4 superimposed upon one another to create a full 360° 3D  
5 image. It should be noted that even when using only  
6 one photograph, the user can manipulate the 3D image to  
7 look at the tree 126 from all angles.

8  
9 It should also be noted that having a bitmap (colour)  
10 image of the tree 126 (and image 124) allows accurate  
11 (true) colours to be assigned to each pixel within the  
12 image. Conventionally, colours are assigned from a  
13 palette which may not be the true and original colours.

14  
15 The software may also be capable of allowing the user  
16 to select two points within the tree 126 and  
17 calculating the horizontal and vertical distances  
18 between the two points. Thus, it is possible for the  
19 user to determine, for example, the height of the tree  
20 by using the mouse to select a pixel at the top and  
21 bottom of the tree 126. If a building is plotted in 3D  
22 using the above methodology, the software can be used  
23 to determine the height, width and depth of the  
24 building, and also other parameters such as the length  
25 of a window, the height of a door and the like. To  
26 enable the user to select points more accurately, the  
27 software is advantageously provided with zoom  
28 capabilities.

29  
30 The software may also be capable of plotting the  
31 profile of the tree using gradiented colours to show  
32 the horizontal distance, vertical distance and/or range  
33 to each of the pixels within the tree 126 or image 124.

34  
35 Additionally, the software may be capable of allowing  
36 the user to select one or more points whereby a profile

1 of the tree 126 in the plane selected can be shown.  
2 Additionally, the profiles in the x, y and z directions  
3 through one particular point within the image can also  
4 be plotted. It is also possible for the x, y and z  
5 axes to be superimposed on the image, and directional  
6 axes (ie north, south, east and west) can also be  
7 superimposed upon the image.

8  
9 Instead of superimposing the bitmap (digital) image  
10 over the triangular wireframe, the software may be used  
11 to create a shaded image of the target and may also be  
12 capable of changing the position of the light which  
13 illuminates the target.

14  
15 It will also be appreciated that the software can  
16 generate x, y and/or z contours which may be  
17 superimposed over the image.

18  
19 Referring back to Fig. 5, the apparatus 100 can  
20 optionally include a Global Positioning System (GPS)  
21 (not shown). GPS is a satellite navigation system  
22 which provides a three-dimensional position of the GPS  
23 receiver (in this case mounted as part of the survey  
24 apparatus 100) and thus the position of the survey  
25 apparatus 100. The GPS is used to calculate the  
26 position of the apparatus 100 anywhere in the world to  
27 within approximately  $\pm$  25 metres. The GPS calculates  
28 the position of the apparatus 100 locally using  
29 radio/satellite broadcasts which send differential  
30 correction signals to  $\pm$  1 metre. The GPS can also be  
31 used to record the time of all measured data to 1  
32 microsecond.

33  
34 The apparatus 100 advantageously includes an  
35 inclinometer (not shown) and a fluxgate compass (not  
36 shown), both of which would be mounted within the

1 casing 50 (Fig. 2). The fluxgate compass generates a  
2 signal which gives a bearing to the target and the  
3 inclinometer generates a signal which gives the incline  
4 angle to the target. These signals are preferably  
5 digitised so that they are in a machine-readable form  
6 for direct manipulation by the computer 120.

7

8 Thus, in addition to being used to find ranges to  
9 specific targets, the survey apparatus may also be used  
10 to determine the position of objects, such as  
11 electricity pylons, buildings, trees or other man-made  
12 or natural structures. The GPS system can be used to  
13 determine the position of the apparatus 100 anywhere in  
14 the world, which can be recorded. Optionally, the  
15 fluxgate compass within the casing 50 measures the  
16 bearing to the target, which can be used to determine  
17 the position of the target using the reading from the  
18 GPS system and the reading from the fluxgate compass.

19

20 The positional information, the bearing and the  
21 inclination to the target can optionally be  
22 superimposed on the 3D image.

23

24 It should also be noted that the encoders 62, 70 may be  
25 used to determine the bearing to the target instead of  
26 the fluxgate compass. In this case, if the encoder is  
27 given an absolute reference, such as the bearing to an  
28 electricity tower or other prominent landmark which is  
29 either known or can be calculated, then the angle  
30 relative to the reference bearing can be calculated  
31 using the outputs from the encoders 62, 70, thus giving  
32 the bearing to the target.

33

34 In addition, the position of the apparatus and the  
35 calculated position of the target could be overlayed on  
36 a map displayed on the computer screen so that the

1 accuracy of the map can be checked. This would also  
2 allow more accurate maps to be drawn.

3  
4 Fig. 18 shows an alternative embodiment of a mounting  
5 device for the surveying apparatus generally designated  
6 150. The apparatus 150 includes a hard-hat type helmet  
7 152. The helmet 152 may be replaced by any suitable  
8 form of headgear, but is used to give a user 154 some  
9 form of protection during use. This is advantageous  
10 where the user 154 is working in hazardous conditions,  
11 such as on a building site, quarry or the like. The  
12 helmet 152 is typically held in place on the head of  
13 the user 154 using a chin strap 156.

14  
15 Mounted within the helmet 152, and preferably  
16 integrally moulded therein, is a Global Positioning  
17 System (GPS) 158. The GPS 158 is a system which  
18 provides a three-dimensional position of the GPS  
19 receiver (in this case mounted within the helmet 152 on  
20 the user 154) and thus the position of the user 154.  
21 The GPS 158 is used to calculate the position of the  
22 user 154 anywhere in the world to within approximately  
23  $\pm$  25 metres. The DGPS calculates the position of the  
24 user 154 locally using radio/satellite broadcasts which  
25 send differential correction signals to  $\pm$  1 metre. The  
26 GPS 158 can also be used to record the time of all  
27 measured data to 1 microsecond.

28  
29 The GPS 158 is coupled to a computer (similar to  
30 computer 120 in Fig. 5) via a serial port. The  
31 computer may be located in a backpack 160, shown  
32 schematically in Fig. 18, or may be a portable  
33 computer, such as a laptop. The backpack 160 has a  
34 power source, such as a battery pack 162, either formed  
35 integrally therewith, or as an external unit.

36

1      Mounted on the helmet 152 is a housing 164 which  
2      encloses the range finder (as shown in Fig. 1), the  
3      video camera 32, an inclinometer (not shown) and a  
4      fluxgate compass (not shown). Signals from the range  
5      finder, camera 32, compass and inclinometer are fed to  
6      the computer in the backpack 160 via a wire harness  
7      166.

8  
9      The fluxgate compass generates a signal which gives a  
10     bearing to the target and the inclinometer generates a  
11     signal which gives the incline angle to the target.  
12     These signals are preferably digitised so that they are  
13     in a machine-readable form for direct manipulation by  
14     the computer.

15  
16     The video camera 32 is preferably a charge-coupled  
17     device (CCD) camera. This type of camera operates  
18     digitally and allows it to be directly interfaced to  
19     the computer in the backpack 160. Signals from the  
20     camera 32 are typically input to the computer via a  
21     video card. The camera 32 may be, for example, a six-  
22     times magnification, monochrome camera with laser  
23     transmitter optics.

24  
25     The view from the camera 32 is displayed on an eyepiece  
26     VGA monitor 168 suspended from the helmet 152. The  
27     monitor 168 is coupled to the computer in the backpack  
28     160 via a second wire harness 170. The monitor 168 is  
29     used to display computer graphics and a generated  
30     graphics overlay.

31  
32     The mounting of the monitor 168 on the helmet 152 is  
33     independent of the housing 164 and is thus adjustable  
34     to suit a plurality of individual users. A tri-axial  
35     alignment bracket (not shown) is provided for this  
36     purpose.

1 In use, software which is pre-loaded on the computer in  
2 the backpack 160 enables the user 154 to see a video  
3 image (provided by the camera 32) of the target on the  
4 monitor 168. The software can overlay the video image  
5 with a sighting graticule (not shown) and any measured  
6 data in a separate window.

7

8 It should be noted from Fig. 1 that the camera 32 and  
9 the laser range finder are bore-sighted. Conventional  
10 systems use an offset eyepiece sighting arrangement  
11 with an axis which is aligned and collimated to be  
12 parallel to the axis of the laser range finder.  
13 However, use of the camera 32 (which displays an image  
14 of the target area on the VGA monitor eyepiece 168)  
15 bore-sighted with the laser range finder provides the  
16 user 154 with an exact view of the target area using  
17 the camera 32. Thus, there is no need for a collimated  
18 eyepiece and the user 154 can be sure that the range  
19 finder will be accurately directed at the target. To  
20 further improve accuracy, computer controlled graticule  
21 offsets may be generated during a calibration and  
22 collimation procedure to eliminate residual errors of  
23 alignment between the laser range finder and the camera  
24 32. These offset values may be stored in an erasable-  
25 programmable-read-only-memory (EPROM) for repetitive  
26 use.

27

28 Operation of the apparatus 150 is controlled by an  
29 input device 172 connected to the computer via a  
30 keyboard input. The input device 172 typically  
31 comprises a keyboard, keypad, penpad or the like, and  
32 controls different functions of the apparatus 150.

33

34 When an observation or survey is required of a  
35 particular target area, the user 154 views the target  
36 area using the camera 32 and the eyepiece monitor 168.

1 The target area is aligned with the graticule typically  
2 using a small circle (not shown) or a cross as a guide.  
3  
4 The user 154 then fires the apparatus 150 using an  
5 appropriate key or button on the input device 172. The  
6 computer initiates the camera 32 which captures a  
7 digital image of the target area and scans the laser 12  
8 to provide a 3D image of the target area as previously  
9 described. It should be noted that the panning and  
10 tilting of the laser 12 is not achieved by motors 60,  
11 68 as in the Fig. 2 embodiment. In this example, the  
12 part-silvered prism 16 can be moved to scan the laser  
13 over the target to provide range information for each  
14 pixel within the target.  
15  
16 In addition, measurements of the various parameters  
17 such as bearing and incline to the target area are  
18 recorded, digitised and incorporated into the  
19 calculations made by the computer. The global position  
20 of the user 154 and the time of the measurement is also  
21 recorded from the GPS/DGPS 158.  
22  
23 The calculated and/or measured data is then sent from  
24 the computer to the monitor 168 and is displayed in a  
25 window of the image by refreshing the data therein.  
26 This allows the user 154 to see the measured data and  
27 confirm that the correct target area has been  
28 identified and accurately shot by reference to the  
29 freeze frame image and the overlaid data window and  
30 reticule.  
31  
32 The user 154 may then save either the data, image or  
33 both to the memory in the computer using an appropriate  
34 push button (not shown) on the input device 172.  
35 Multiple measurements of this nature may be recorded,  
36 for each pixel, thus giving 3D images of different

1 target areas. These images may then be used to observe  
2 the target area either in real-time or later to assess  
3 and/or analyse any of the geographical features.

4

5 For example, one particular use would be by the  
6 military. During operations, a squad may be required  
7 to cross a river. The survey apparatus may be used to  
8 create multiple 3D images of possible crossing places,  
9 for example by deploying the apparatus on an elevated  
10 platform. These would then be assessed to select the  
11 best location for a mobile bridge to be deployed. The  
12 image may be viewed locally or could be transmitted in  
13 a digital format to a command post or headquarters  
14 anywhere in the world. Use of the survey apparatus  
15 would result in much faster and more accurate  
16 observations of the geographical locations and would  
17 avoid having to send soldiers into the area to visually  
18 assess the locations and report back. The apparatus  
19 may be deployed on an elevated platform and operated by  
20 remote control to decrease the risk to human users in  
21 hostile situations.

22

23 Referring to Figs 19a to 19c, there is shown a vehicle  
24 180 (such as a tank) which is provided with the  
25 apparatus 100 of Figs 2 and 3 mounted on a telescopic  
26 or extendable arm 182. As illustrated in Fig. 19a, the  
27 apparatus 100 may be completely retracted when the  
28 vehicle 180 is in motion, and may be stored behind an  
29 armoured shield 184. The casing 50 of the apparatus  
30 100 would tilt downwards to a horizontal attitude and  
31 the telescopic arm 182 would extend so that the  
32 apparatus 100 was substantially protected by the  
33 armoured shield 184.

34

35 When the area to be surveyed is reached, the vehicle is  
36 stopped and the apparatus 100 deployed on the

1 telescopic arm 182 by reversing the procedure described  
2 above, as illustrated in Fig. 19b. The telescopic arm  
3 182 is preferably mounted on a rotation joint 186 so  
4 that the apparatus 100 can be rotated through 360° as  
5 indicated by arrow 188 in the enlarged portion of Fig.  
6 19b. A motor 190 is coupled to the rotation joint 186  
7 to facilitate rotation of the joint 186. The apparatus  
8 100 can typically be raised to a height of  
9 approximately 15 metres or more, depending upon the  
10 construction of the arm 182.

11  
12 The particular configuration shown in Figs 19a and 19b  
13 can accommodate large angles of roll and pitch of the  
14 vehicle, such as that shown in Fig. 19c. In Fig. 19c,  
15 the vehicle 180 is stationary on a slope 192 and has  
16 been rolled through an angle indicated by arrow 184 in  
17 Fig. 19c. The user or the computer can correct for the  
18 angle of roll 184 by moving the arm 182 until the  
19 inclinometer indicates that the apparatus 100 is level.  
20 A level 198 (Figs 20a, 20b) may be provided on the base  
21 of the apparatus 100 if required.

22  
23 Figs 20a and 20b are front and side elevations of the  
24 apparatus 100 mounted on the arm 182. As can be seen  
25 from Figs 20a and 20b, the arm 182 can be rotated  
26 through 360° as indicated by arrow 196 in Fig. 20a.  
27 The apparatus 100 is mounted on a pan and tilt head 200  
28 to facilitate panning and tilting of the apparatus 100.

29  
30 Servo motors within the pan and tilt head 200 pan and  
31 tilt the head 200 into the plane of roll and pitch of  
32 the vehicle 180 (Fig. 19c). Thereafter, the motors 60,  
33 68 of the apparatus 100 pan and tilt the apparatus 100  
34 until it is level, using the level indicator 198 as a  
35 guide.

32

1 Further electronic levels (not shown) within the  
2 apparatus 100 can measure any residual dislevelment and  
3 this can be corrected for in the software before any  
4 measurements are taken.

5

6 A particular application of the apparatus 100 deployed  
7 on a vehicle 180 would be in a military operation. The  
8 apparatus 100 can be deployed remotely on the arm 182  
9 and used to survey the area surrounding the vehicle 180  
10 to create a 3D real-time image of the terrain.

11

12 Alternatively, or additionally, the computer 120 could  
13 be provided with a ground modelling software package  
14 wherein the user selects a number of key targets within  
15 the area using the method described above, and finds  
16 the range and bearing to, height of and global position  
17 of (if required) these targets. The software package  
18 will then plot these points, including any heights  
19 which a GPS 202 (Figs 20a and 20b) can generate, and  
20 in-fill or morph the remaining background using digital  
21 images captured by the camera 32 to produce a 3D image  
22 of the terrain, as described above.

23

24 The surveying operation can be done discretely and in a  
25 very short time compared with conventional survey  
26 techniques and provides a real-time 3D image of the  
27 terrain. Once the terrain has been modelled, design  
28 templates of equipment carried by the vehicle 180 (or  
29 any other vehicle, aircraft etc) can be overlayed over  
30 the image to assess which type of equipment is required  
31 to cross the obstacle, such as a river.

32

33 Conventional techniques would typically require to  
34 deploy a number of soldiers to survey the area manually  
35 and report back. However, with the apparatus 100  
36 deployed on the vehicle 180 the survey can be done

1 quicker, more accurately and more safely, without  
2 substantial risk to human life.

3  
4 It is possible to conduct multiple surveys with the  
5 vehicle 180 in one or more locations, with the data  
6 from each survey being integrated to give a more  
7 accurate overall survey of the surrounding area.

8  
9 Furthermore, if the arm 182 was disposed at the front  
10 of the vehicle 160 as shown in Figs 21a and 21b, the  
11 apparatus 100 can be used to check the profile of the  
12 ground in front of the vehicle 180. Thus, the profile  
13 of the ground could be shown in 3D which would allow  
14 the driver of the vehicle (or other personnel) to  
15 assess the terrain and warn of any dangers or  
16 difficulties.

17  
18 Alternatively, or additionally, the software on the  
19 computer 120 could be used to generate a head-up video  
20 display to which the driver of the vehicle 180 could  
21 refer. The heading of the tank (measured by the  
22 fluxgate compass) could also be displayed, with the  
23 range to and height of the ground (and any  
24 obstructions) in front of the vehicle 180 also being  
25 displayed. The height displayed could be the height  
26 relative to the vehicles' position, or could be the  
27 absolute height obtained from the GPS 202.

28  
29 Another application of the survey apparatus 110 would  
30 be to capture images of electricity pylons for example  
31 by targeting each individually and saving the data for  
32 future reference (for example to allow their positions  
33 on a map to be plotted or checked) or to observe them  
34 in 3D to check for any faults or the like.

35  
36 In addition to providing the 3D image of the target

1 area, the computer may also calculate the position of  
2 the target area using the GPS/DGPS 158 (Fig. 18). The  
3 position of the user 154 is recorded using the GPS/DGPS  
4 158, and by using the measurements such as bearing and  
5 inclination to the target area, the position of the  
6 target area may thus be calculated.

7  
8 The apparatus provides a 3D image of the target area  
9 which, in a geographical format, may be used to update  
10 map information and/or object dimensions and positions.  
11 The software may overlay and annotate the measured  
12 information on background maps which may be stored, for  
13 example, on compact-disc-read-only-memory (CD-ROM) or  
14 any other data base, such as Ordinance Survey maps.

15  
16 Using a separate function on the input device 172, the  
17 user can change the image on the monitor 168 to show  
18 either a plot of the user's position (measured by the  
19 GPS/DGPS 158) superimposed on the retrieved data base  
20 map, or to view updated maps and/or object dimensions  
21 and positions derived from the measurements taken by  
22 the apparatus 100.

23  
24 Fig. 22 shows a concept design of an alternative  
25 apparatus 210. The apparatus 210 is mounted on a head  
26 band 212 which rests on the head of a user 214.  
27 Mounted on the headband 212 is a housing 224 which is  
28 attached to the headband 212. The housing 224 encloses  
29 the survey apparatus 100 (Fig. 5) as previously  
30 described. This particular embodiment incorporates an  
31 eyepiece monitor 250 into the housing 224.

32  
33 Figs 23 to 30 show a hand-held housing for the survey  
34 apparatus. The hand-held device 300 includes an  
35 eyepiece 310 which is used to select the target area.  
36 Device 300 includes an image capture and laser

1 transmitter and receiver unit 10 similar to that shown  
2 schematically in Fig. 1.

3

4 In use, a user 314 (Figs 28 to 30) puts the eyepiece  
5 310 to his eye and visualises the target through a lens  
6 312. When the target has been visualised, a fire  
7 button 314 is depressed which initiates the camera 32  
8 (Fig. 1) to take a digital (two-dimensional) image of  
9 the target, which can be displayed on a small LCD  
10 screen 316. The laser range finder can then be used to  
11 determine the range to each pixel using the methodology  
12 described herein to allow a 3D image to be produced.  
13 It should be noted that the hand-held device 300 need  
14 not be capable of processing the 3D image. The range  
15 to each pixel can be recorded and stored in a file for  
16 transfer to a computer (provided with the appropriate  
17 software) which may be used to reproduce the 3D image.  
18 The device 300 is typically provided with a suitable  
19 interface for downloading, or may be provided with an  
20 alternative storage means such as an EPROM which may be  
21 removed from the device as required, or a floppy disc  
22 drive for example.

23

24 Thus, there is provided a survey apparatus which is  
25 capable of producing 3D images, both in real-time and  
26 for later viewing. The apparatus may be mounted in a  
27 hand-held device or on the head of a user. The  
28 apparatus may also be mounted on a tripod stand or on  
29 an elevated platform. Furthermore, the images may be  
30 stored or electronically transmitted for subsequent  
31 retrieval and analysis.

32

33 The apparatus is simpler, cheaper and has the  
34 capability to be more accurate than current techniques  
35 used to produce 3D images.

36

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36

1 Modifications and improvements may be made to the  
2 foregoing without departing from the scope of the  
3 invention.

4

5

6

/u/mur/specs21/p21397-

APPENDIX A

Point Number	Pixel x (Px)	Pixel y (Py)	x	y	z
1	46	564	118.832	-51.694	21.918
2	226	565	118.016	-53.833	21.963
3	404	567	116.851	-55.760	21.945
4	581	569	115.320	-57.496	21.864
5	737	569	113.575	-58.796	21.700
6	742	378	113.504	-58.835	19.403
7	753	187	114.939	-59.731	17.352
8	756	84	114.961	-59.794	16.117
9	577	88	117.057	-58.311	16.312
10	398	96	118.512	-56.477	16.468
11	219	98	119.685	-54.493	16.520
12	46	101	119.220	-51.863	16.378
13	46	292	119.067	-51.797	18.665
14	47	485	118.883	-51.741	20.976
15	46	107	119.194	-51.852	16.444
16	46	132	119.205	-51.857	16.745
17	46	159	119.231	-51.868	17.072
18	46	185	119.201	-51.855	17.391
19	46	210	119.210	-51.859	17.692
20	74	556	118.765	-52.060	21.840
21	74	535	118.767	-52.061	21.584
22	74	510	118.775	-52.064	21.283
23	74	483	118.795	-52.073	20.962
24	74	457	118.724	-52.042	20.624
25	74	428	118.457	-51.925	20.231
26	74	399	118.758	-52.057	19.934
27	74	371	118.778	-52.066	19.590
28	74	344	118.768	-52.061	19.265
29	74	315	120.100	-52.645	19.130
30	74	287	120.291	-52.729	18.809
31	74	258	120.326	-52.744	18.464
32	74	229	120.352	-52.756	18.117
33	74	201	120.350	-52.755	17.767
34	74	174	120.353	-52.756	17.440
35	74	143	120.352	-52.755	17.067
36	74	117	120.353	-52.756	16.741
37	101	109	120.243	-53.084	16.651
38	101	134	120.245	-53.084	16.955
39	101	161	120.243	-53.084	17.281

## APPENDIX A

Point Number	Pixel x (Px)	Pixel y (Py)	x	y	z
40	101	187	120.249	-53.086	17.609
41	101	214	120.255	-53.089	17.937
42	101	243	120.220	-53.074	18.282
43	101	269	120.224	-53.075	18.610
44	101	298	120.216	-53.072	18.960
45	101	325	119.530	-52.769	19.178
46	101	353	118.652	-52.381	19.384
47	101	380	118.689	-52.398	19.714
48	101	407	118.582	-52.350	20.020
49	101	434	118.311	-52.231	20.298
50	101	462	118.668	-52.388	20.708
51	101	489	118.694	-52.400	21.037
52	101	518	118.688	-52.397	21.385
53	101	544	118.667	-52.388	21.707
54	128	544	118.556	-52.710	21.712
55	128	529	118.566	-52.715	21.528
56	128	506	118.571	-52.717	21.249
57	128	480	118.573	-52.718	20.924
58	128	455	118.517	-52.693	20.612
59	128	426	118.250	-52.574	20.219
60	128	399	118.538	-52.702	19.944
61	128	371	118.576	-52.719	19.602
62	128	344	118.566	-52.714	19.276
63	128	315	120.013	-53.358	19.160
64	128	287	120.112	-53.402	18.825
65	128	258	120.112	-53.402	18.474
66	128	229	120.128	-53.409	18.126
67	128	201	120.126	-53.408	17.775
68	128	174	120.120	-53.406	17.447
69	128	143	120.128	-53.409	17.074
70	128	117	120.130	-53.410	16.748
71	155	109	120.000	-53.729	16.656
72	155	134	120.010	-53.734	16.961
73	155	161	120.008	-53.733	17.287
74	155	187	120.006	-53.731	17.614
75	155	214	120.020	-53.738	17.943
76	155	243	119.986	-53.723	18.289
77	155	269	119.981	-53.720	18.616
78	155	298	119.981	-53.721	18.967

APPENDIX A

Point Number	Pixel x (Px)	Pixel y (Py)	x	y	z
79	155	325	119.298	-53.414	19.185
80	155	352	118.424	-53.023	19.368
81	155	378	118.462	-53.040	19.699
82	155	407	118.369	-52.999	20.031
83	155	434	118.090	-52.873	20.308
84	155	462	118.437	-53.029	20.716
85	155	489	118.472	-53.045	21.047
86	155	518	118.457	-53.038	21.393
87	155	544	118.436	-53.029	21.715
88	182	544	118.315	-53.347	21.719
89	182	529	118.315	-53.347	21.532
90	182	506	118.320	-53.349	21.254
91	182	480	118.331	-53.354	20.931
92	182	455	118.266	-53.325	20.617
93	182	426	118.018	-53.213	20.227
94	182	399	118.297	-53.338	19.950
95	182	371	118.335	-53.356	19.608
96	182	344	118.306	-53.343	19.279
97	182	315	119.741	-53.990	19.162
98	182	287	119.858	-54.043	18.829
99	182	258	119.858	-54.042	18.478
100	182	229	119.874	-54.050	18.130
101	182	201	119.863	-54.045	17.777
102	182	174	119.875	-54.050	17.452
103	182	143	119.865	-54.045	17.077
104	182	117	119.866	-54.046	16.751
105	208	109	119.735	-54.365	16.659
106	208	134	119.736	-54.365	16.962
107	208	161	119.734	-54.364	17.289
108	208	187	119.732	-54.363	17.615
109	208	214	119.755	-54.374	17.946
110	208	241	119.715	-54.356	18.267
111	208	269	119.707	-54.352	18.617
112	208	196	119.701	-54.349	18.944
113	208	325	119.061	-54.059	19.192
114	208	352	118.163	-53.651	19.371
115	208	378	118.200	-53.668	19.702
116	208	407	118.099	-53.622	20.033
117	208	434	117.820	-53.495	20.309

## APPENDIX A

Point Number	Pixel x (Px)	Pixel y (Py)	x	y	z
118	208	460	118.170	-53.654	20.695
119	208	487	118.187	-53.662	21.023
120	208	516	118.190	-53.663	21.372
121	208	544	118.166	-53.652	21.717
122	235	544	118.034	-53.965	21.719
123	235	529	118.034	-53.966	21.532
124	235	506	118.039	-53.968	21.254
125	235	480	118.050	-53.973	20.931
126	235	453	117.980	-53.941	20.593
127	235	426	117.728	-53.826	20.225
128	235	399	118.016	-53.957	19.950
129	235	371	118.045	-53.970	19.607
130	235	344	118.025	-53.961	19.279
131	235	315	118.988	-54.402	19.087
132	235	287	119.439	-54.608	18.808
133	235	258	119.528	-54.649	18.471
134	235	229	119.554	-54.660	18.124
135	235	201	119.569	-54.667	17.776
136	235	174	119.545	-54.656	17.445
137	235	143	119.544	-54.656	17.072
138	235	117	119.546	-54.657	16.746
139	260	109	118.016	-54.306	16.458
140	260	134	118.009	-54.303	16.756
141	260	161	118.017	-54.307	17.080
142	260	187	118.014	-54.306	17.403
143	260	214	118.038	-54.317	17.730
144	260	243	118.050	-54.322	18.078
145	260	269	117.991	-54.295	18.393

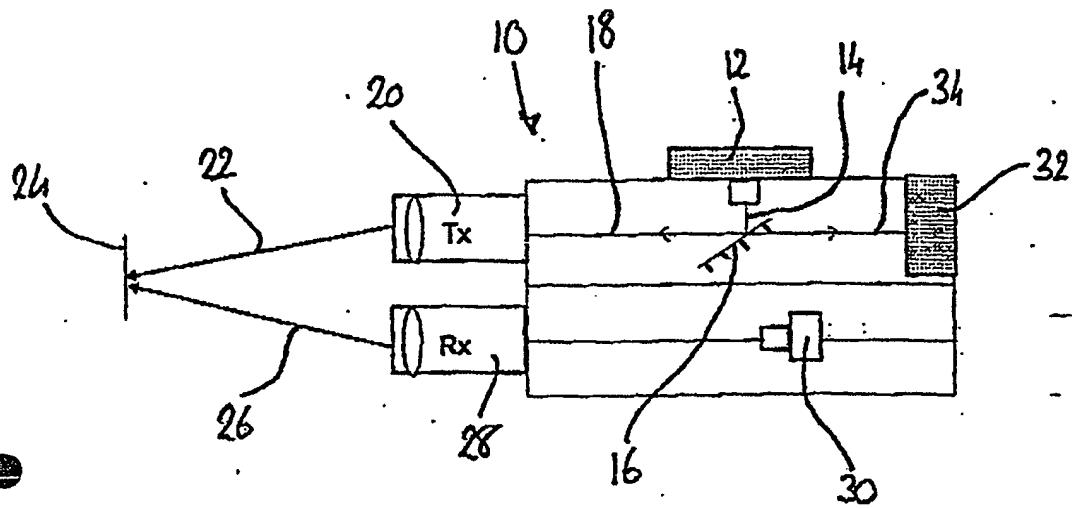


FIG. 1

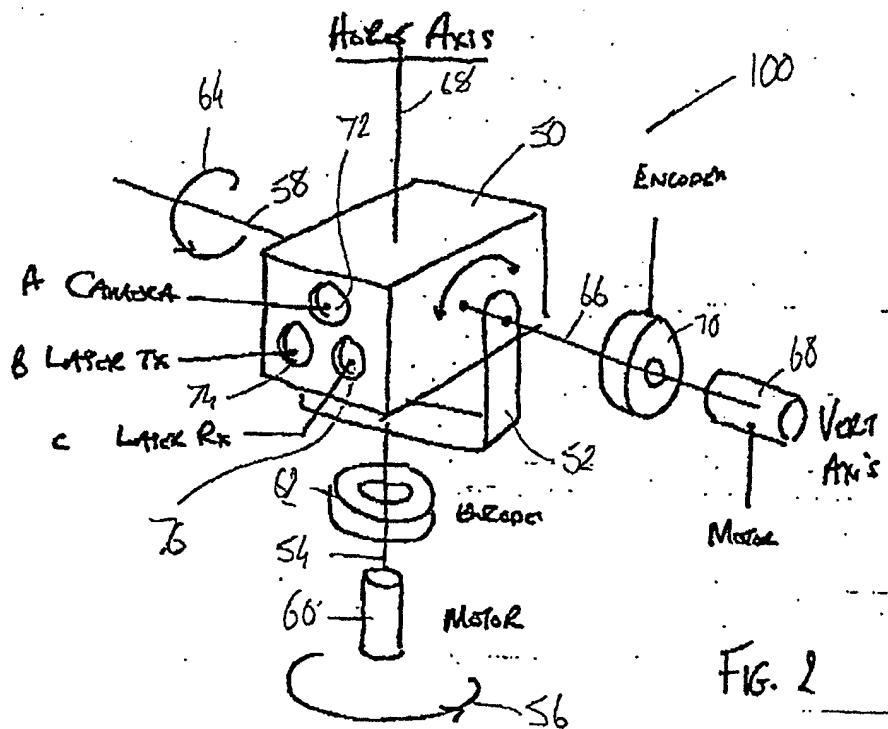


FIG. 2

(DEBLLY A,B,C WOULD BE CO AXIAL

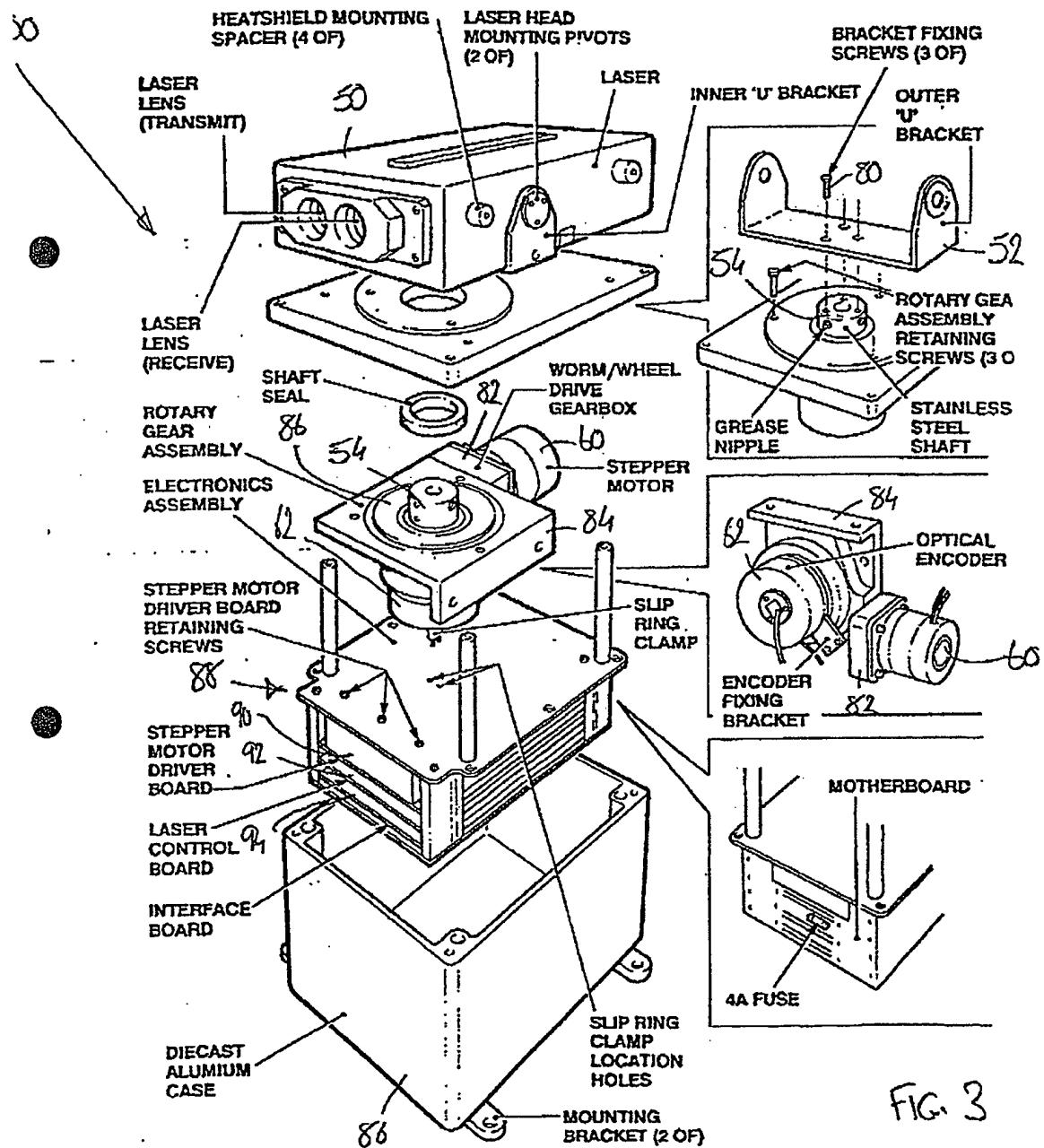


FIG. 3

Fig. 3 - Scanning Head - exploded view

1 Axis

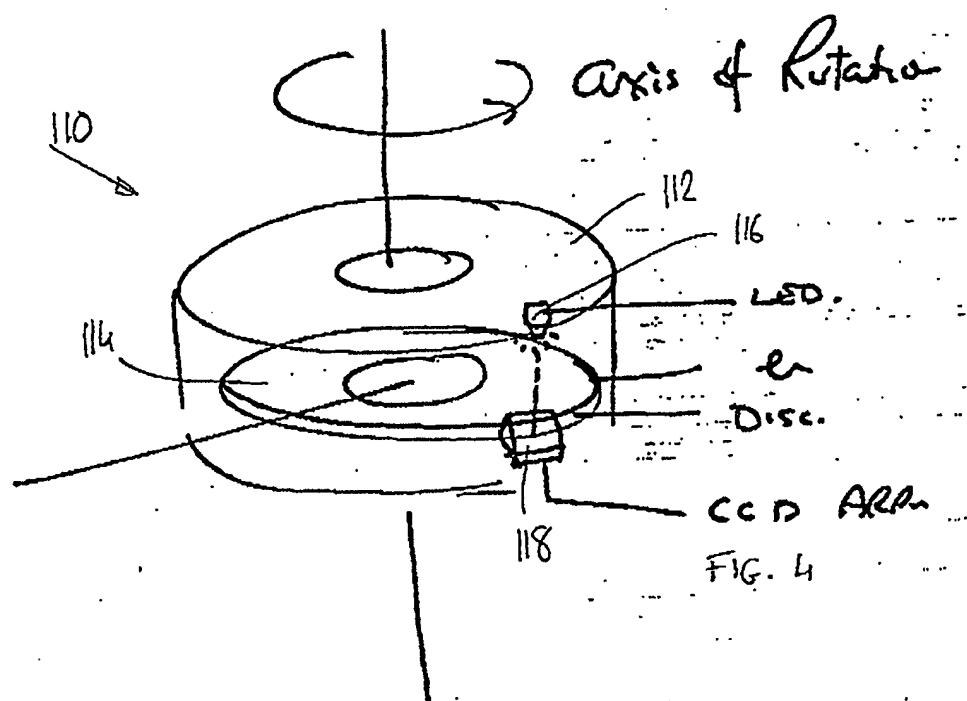


FIG. 4

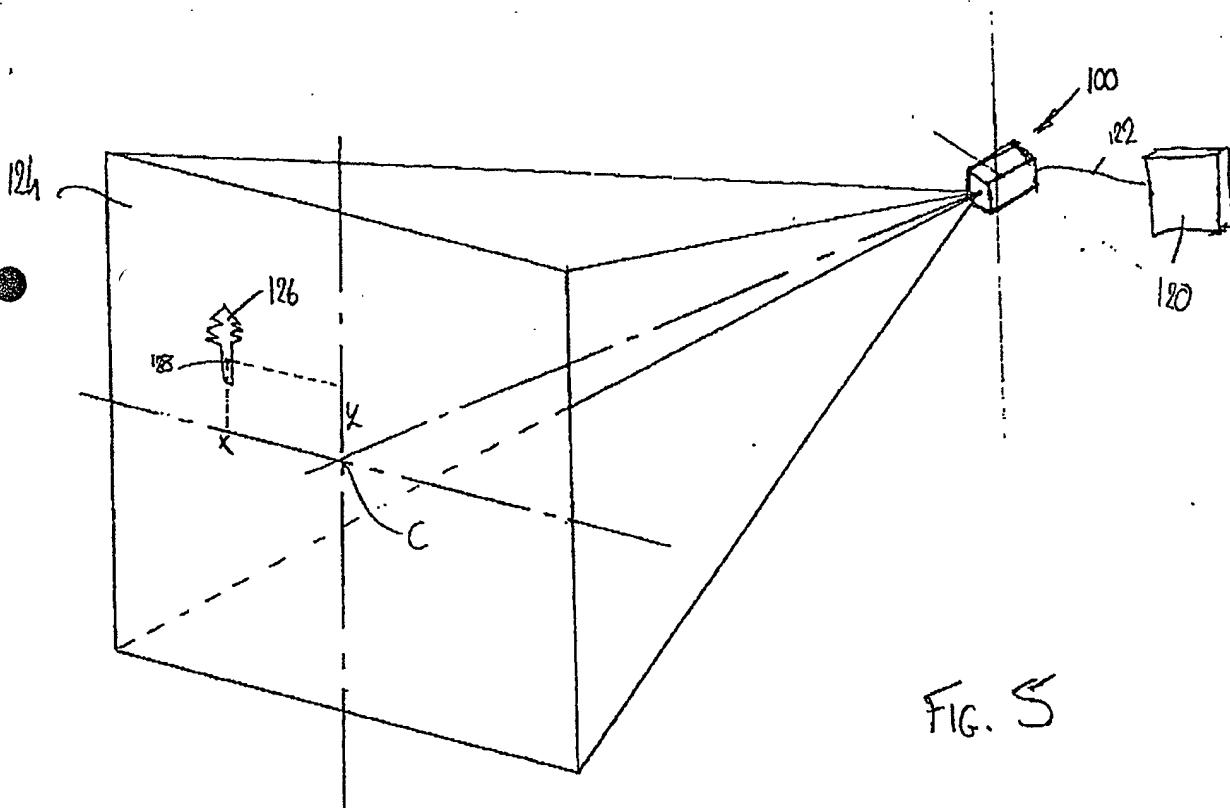


FIG. 5

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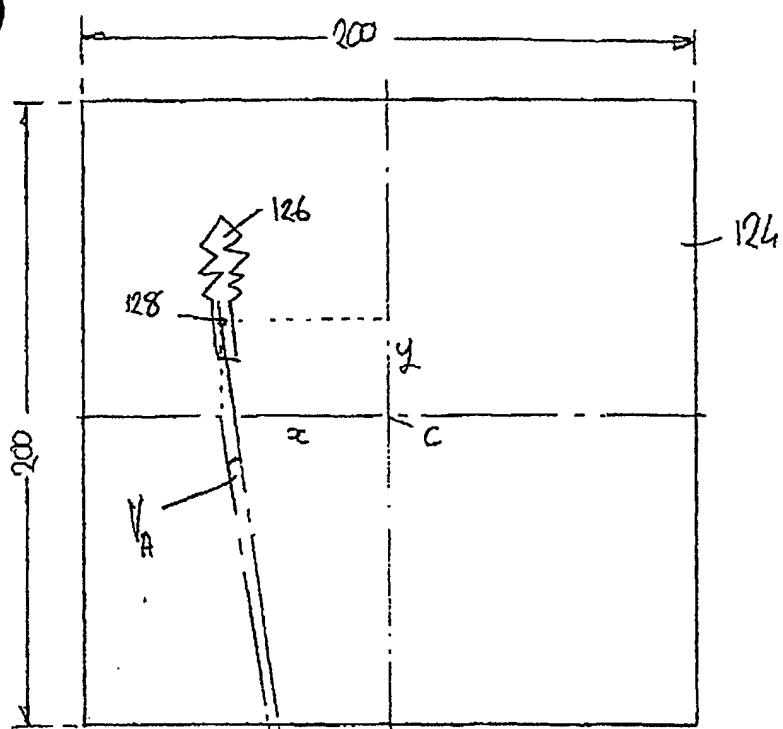


FIG. 6



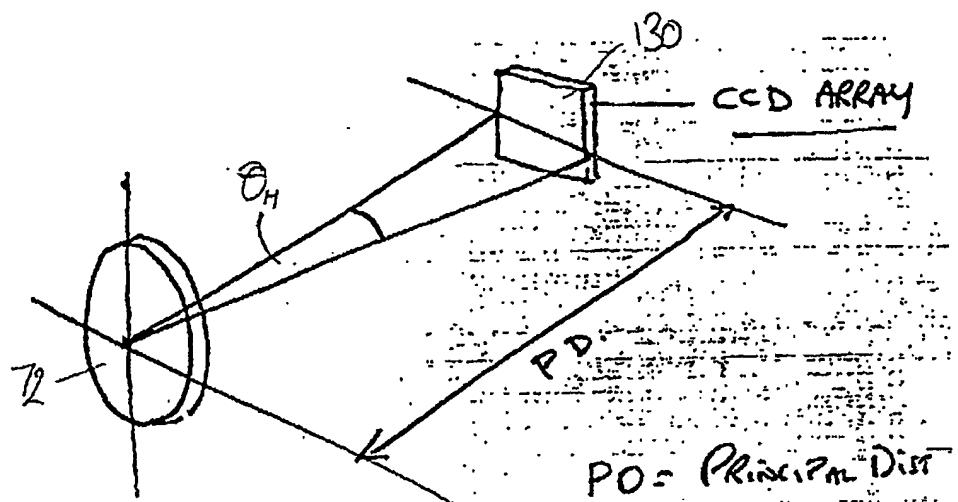


FIG. 7

P0 = Principal Dist

θ = Field of View  
(or field angle).

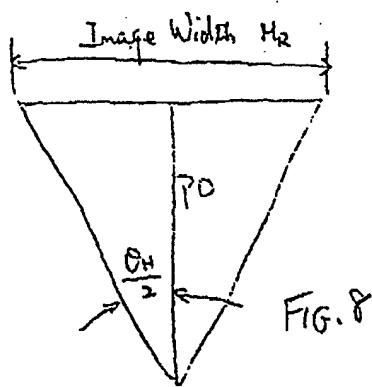


FIG. 8

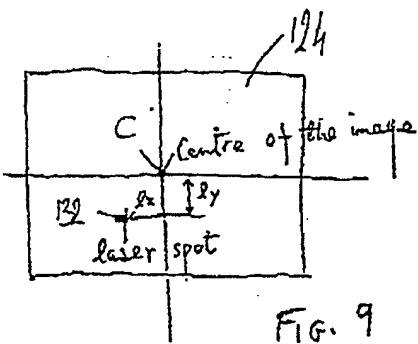


FIG. 9

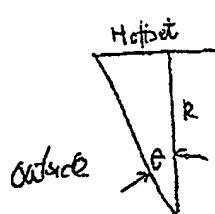


FIG. 10

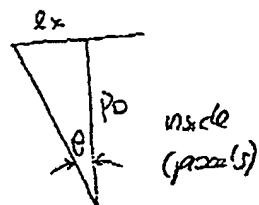


FIG. 11

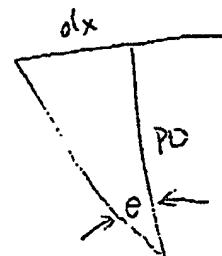
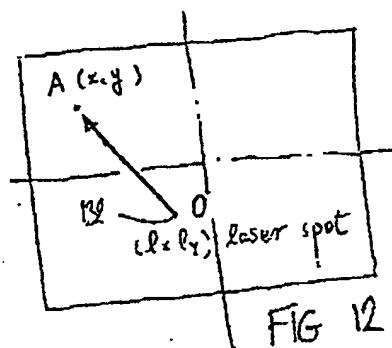


FIG. 13.

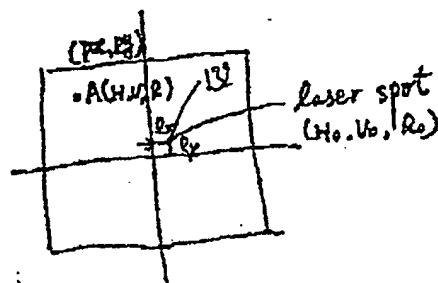


FIG. 14

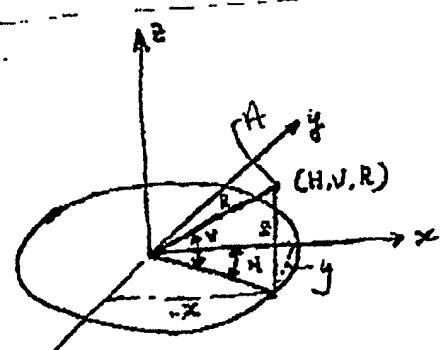
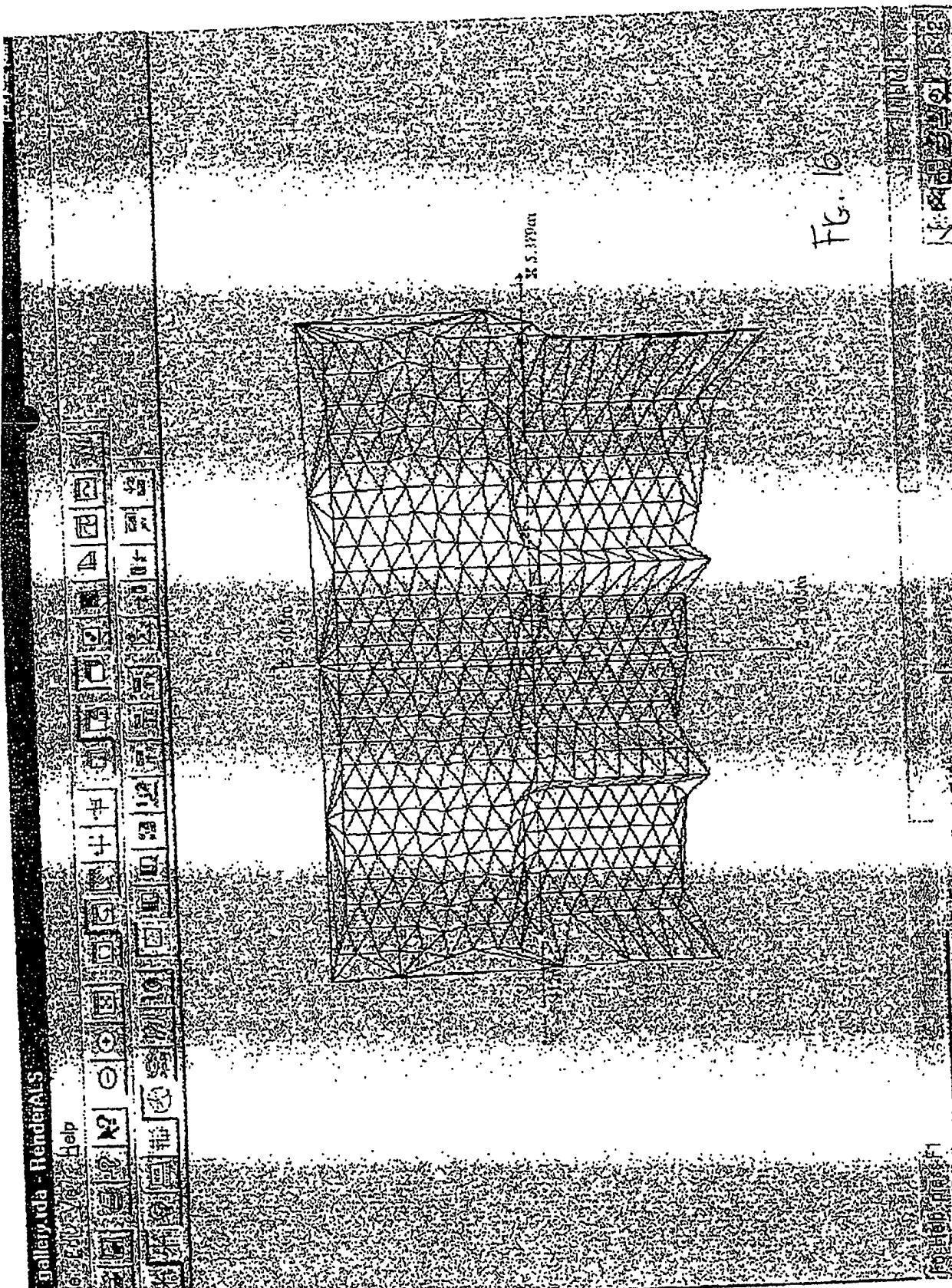


FIG. 15

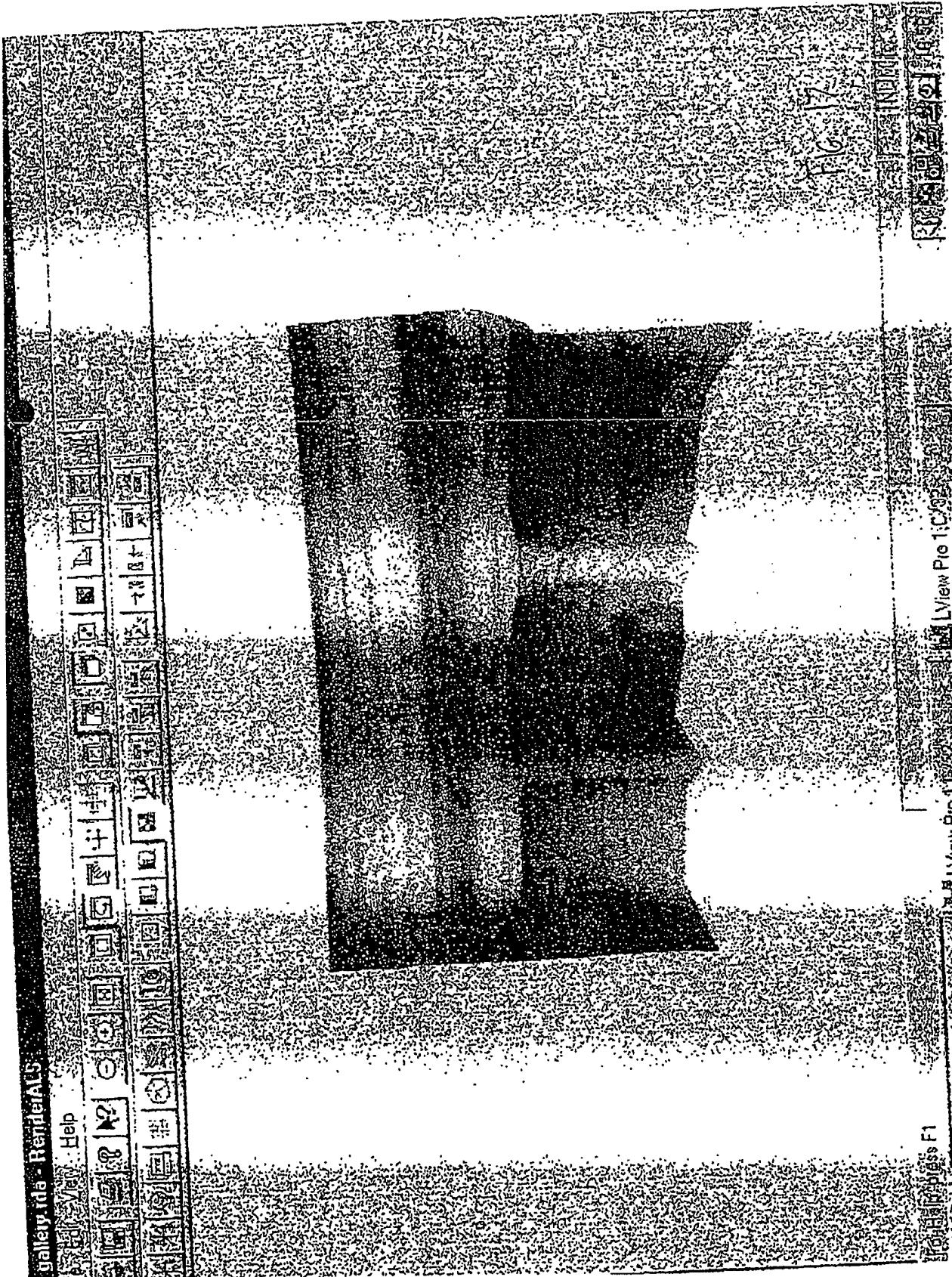
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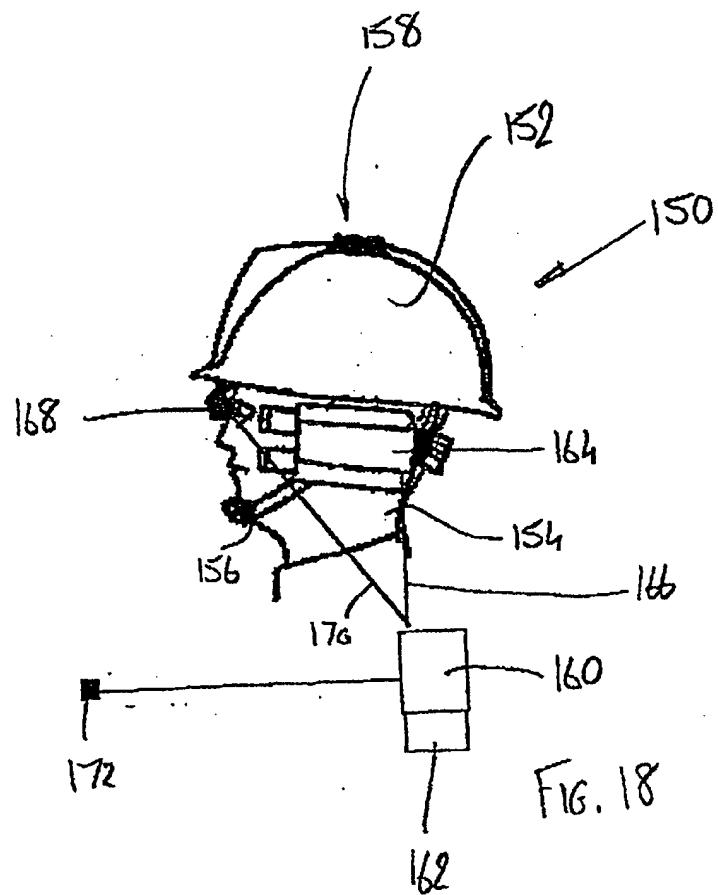
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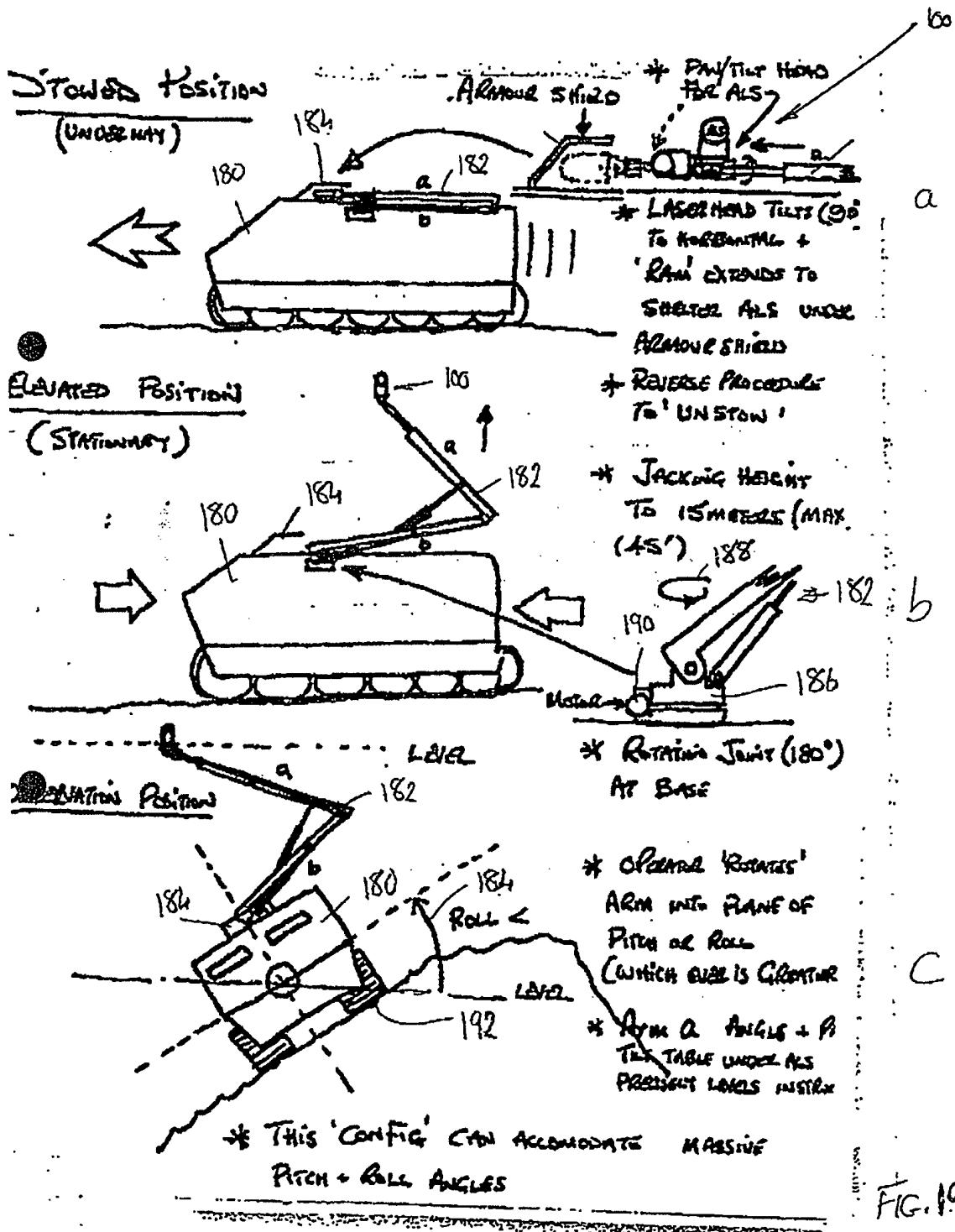
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## Toneff Tit Solution • DEKA (Gauze)

Optimum Design  
For Retraction and  
Protective Toward Tissue

Method: Schrödinger

ROTARYS. FIGS. 17 AND 18.

INTO FINNIE OFF RENT

From [Title] to [Label]  
Mount [Title]

Electronic levels in  
the muscle receptors  
disinhibit + excite the  
apparatus in Software

Digitized by Google

Applieo in Software

Mr. MAN PRESENTED:—

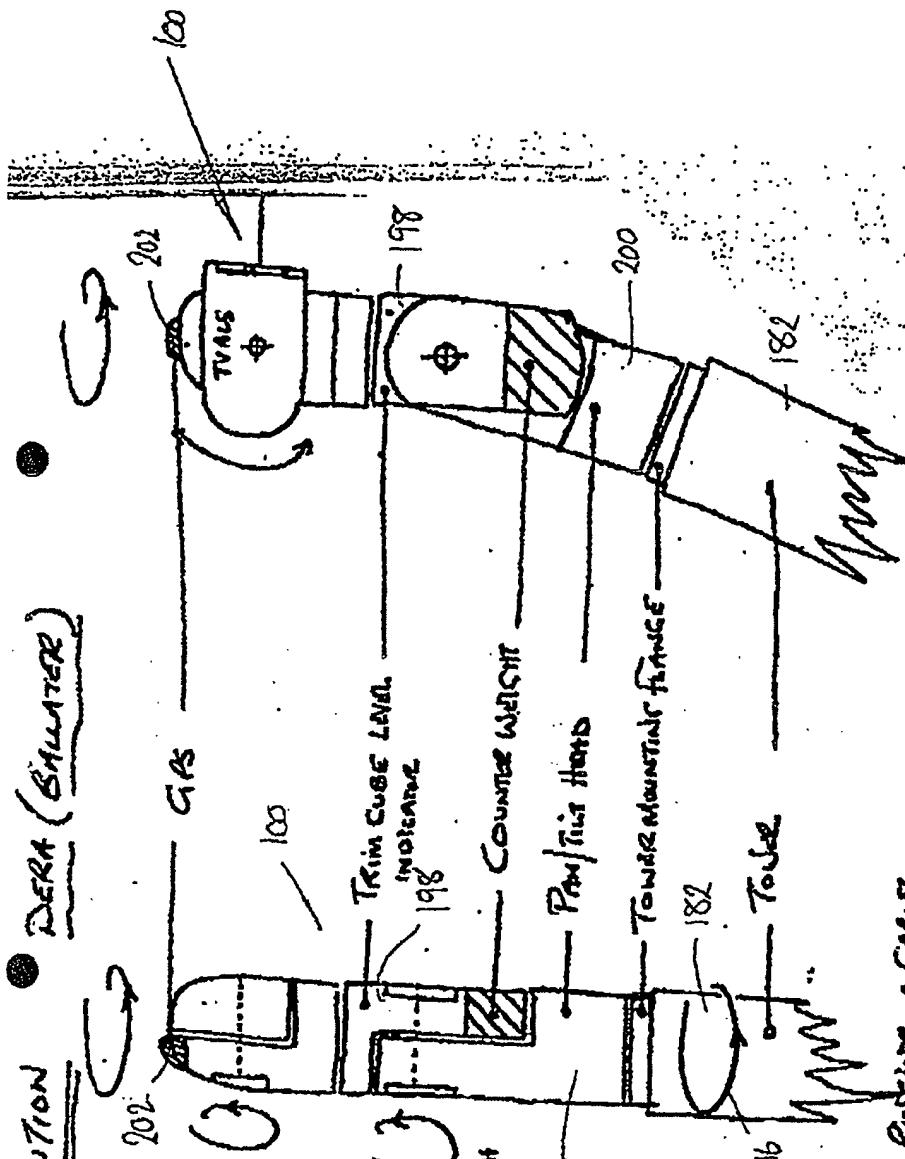


Fig. 20a. *W. tenuis* sp. n. (♂). Fig. 20b.

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Job-686

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SCHEMATIC

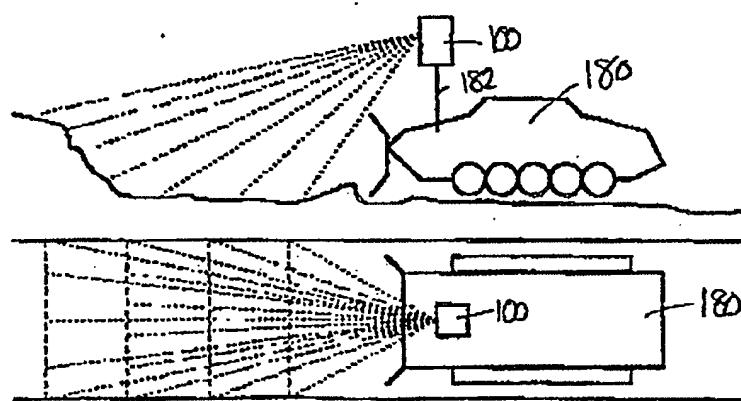
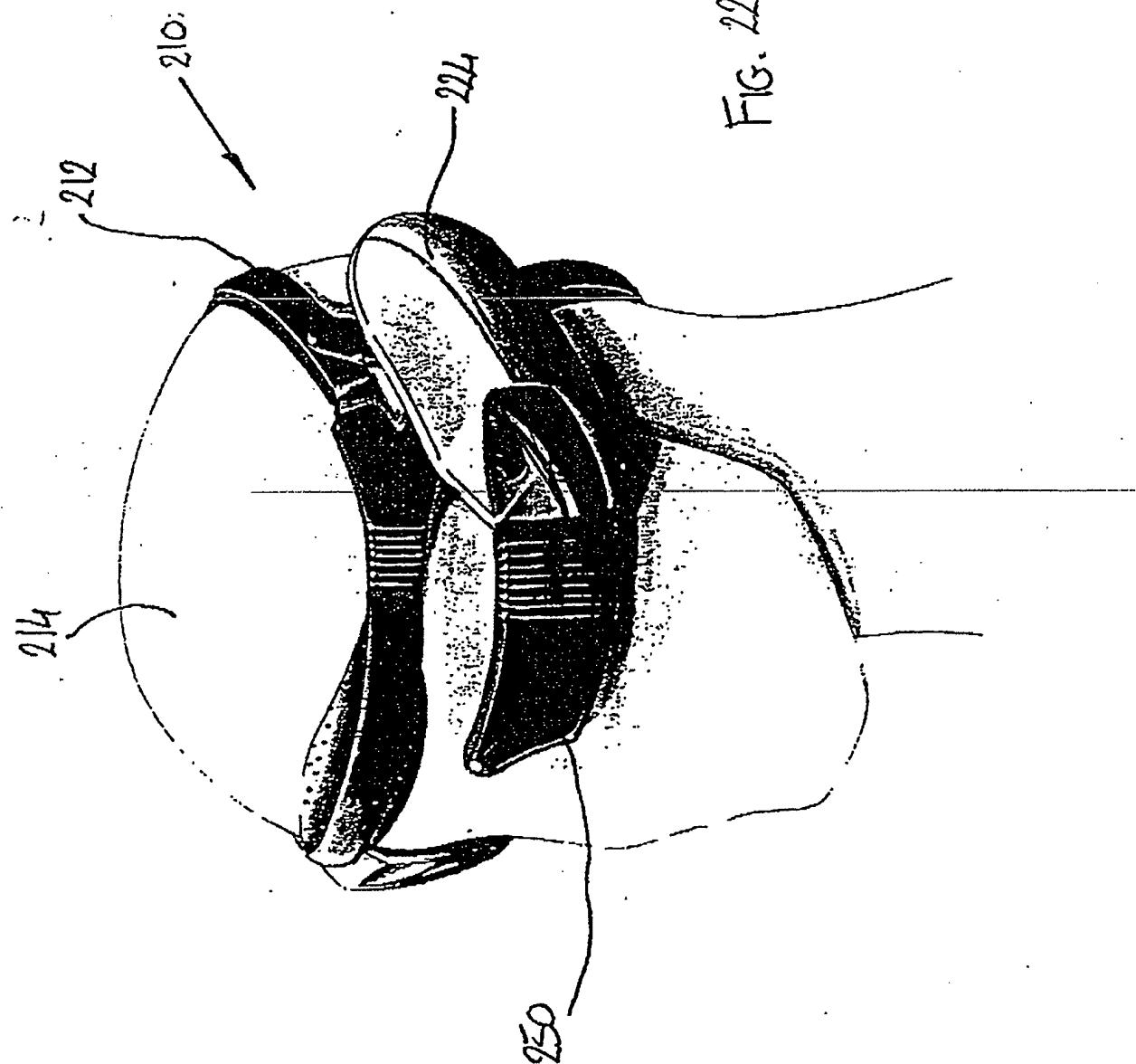


FIG. 21a

FIG. 21b



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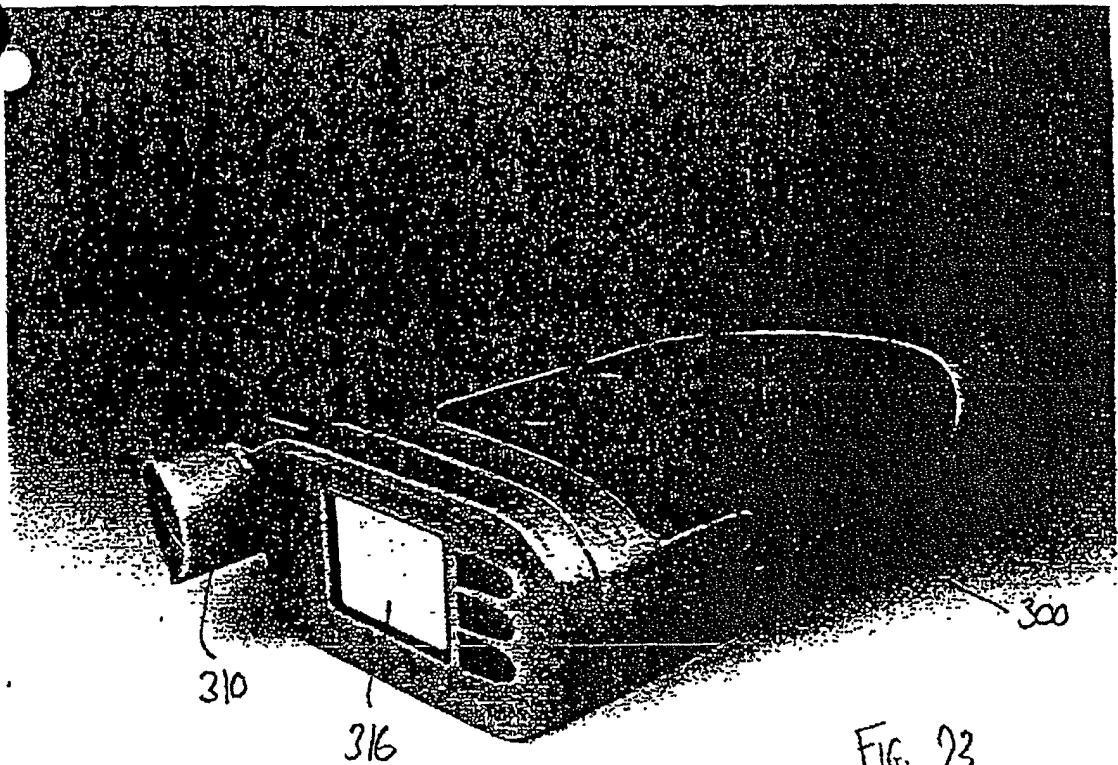


FIG. 23

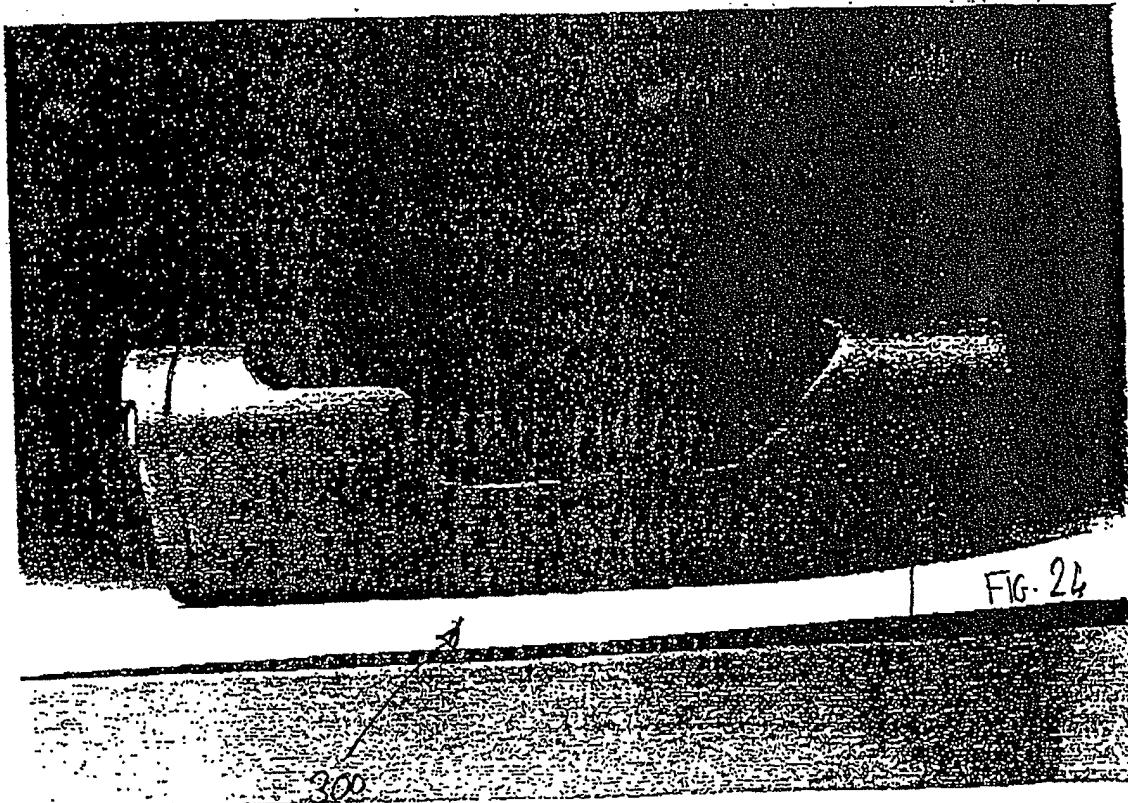


FIG. 24

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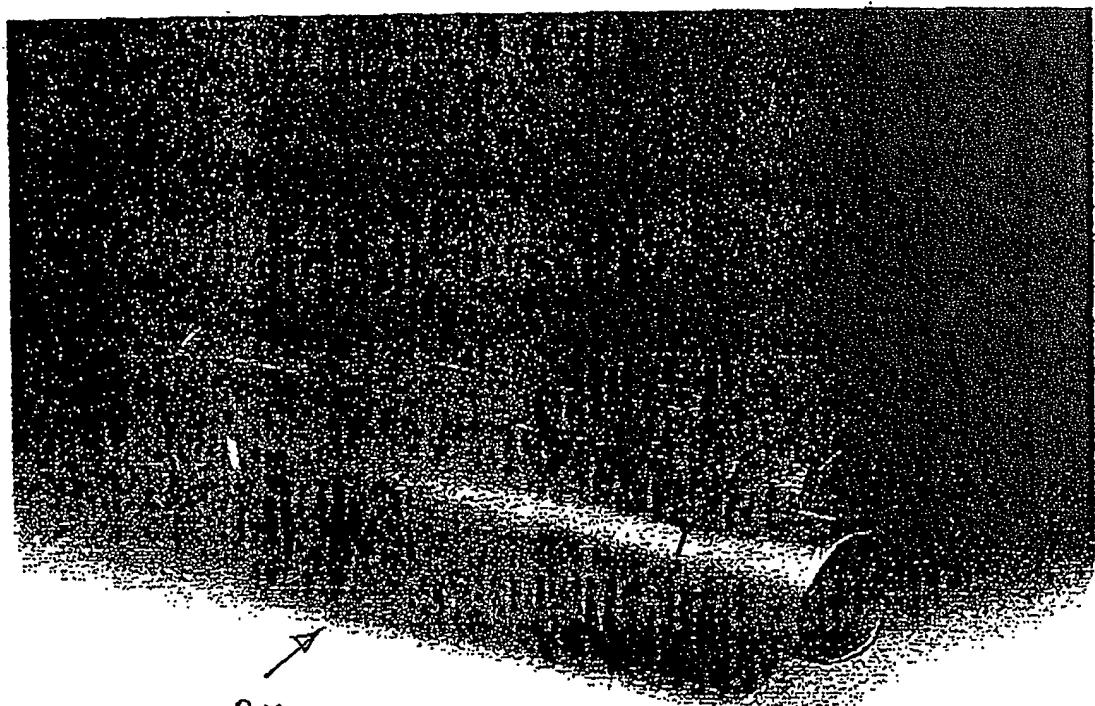
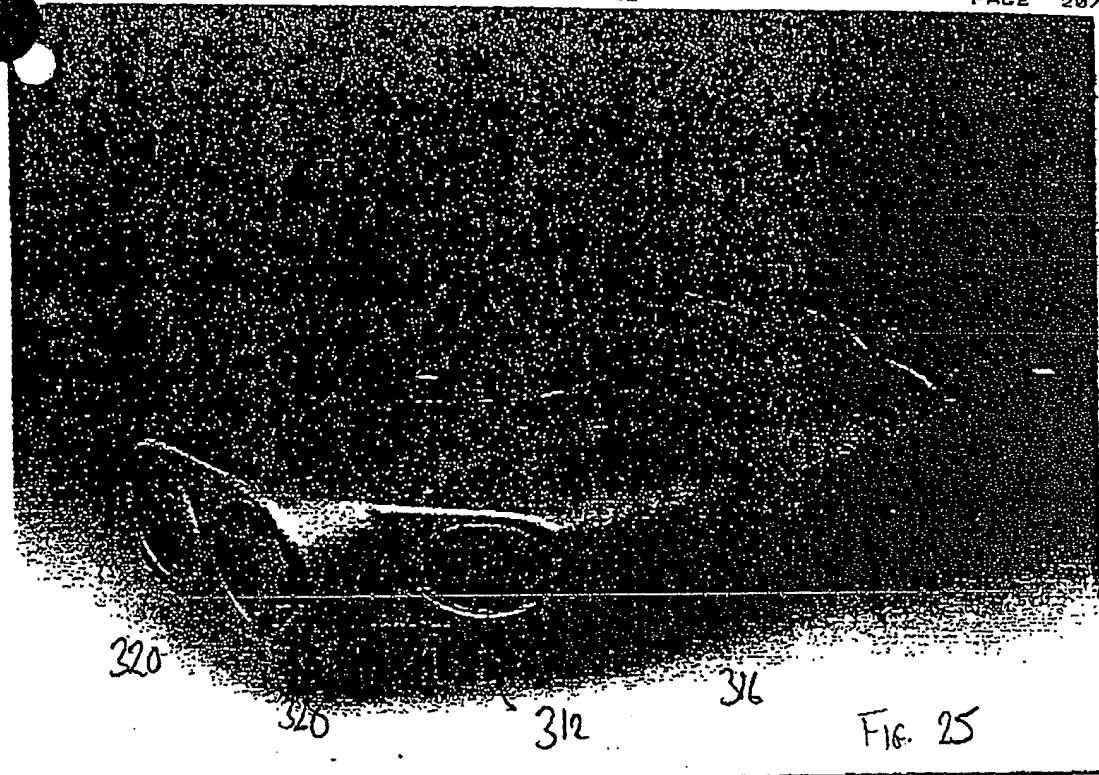
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Job-686

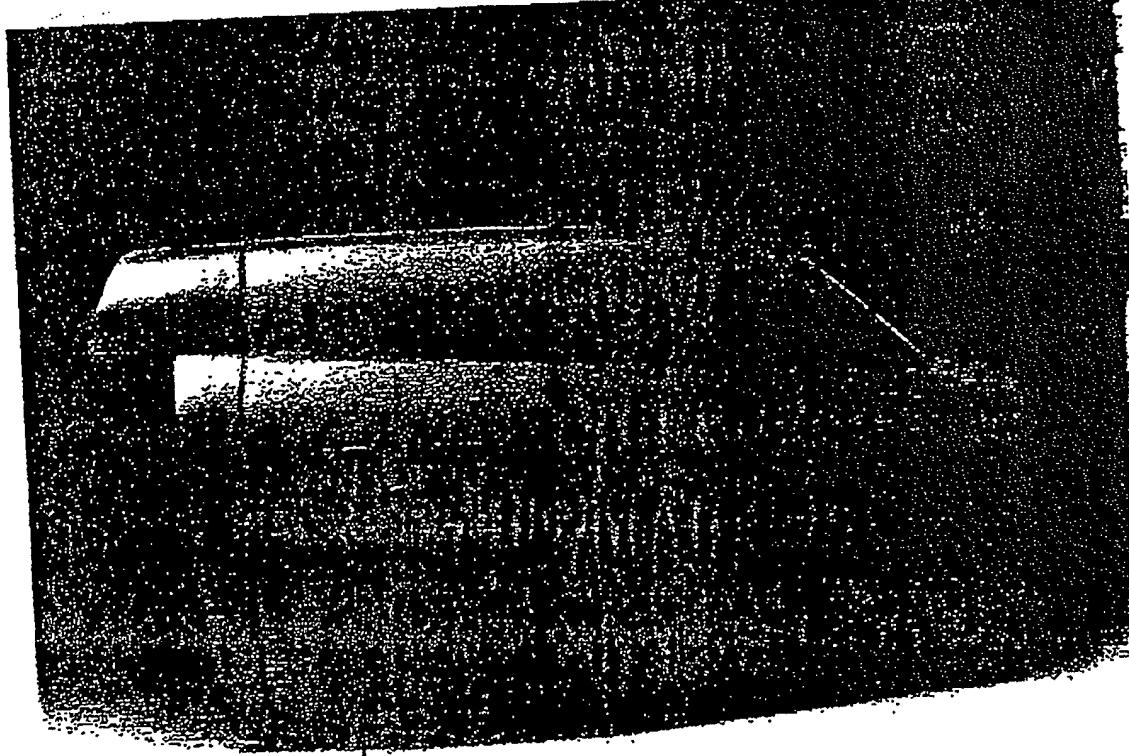
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1

300

Fig. 27

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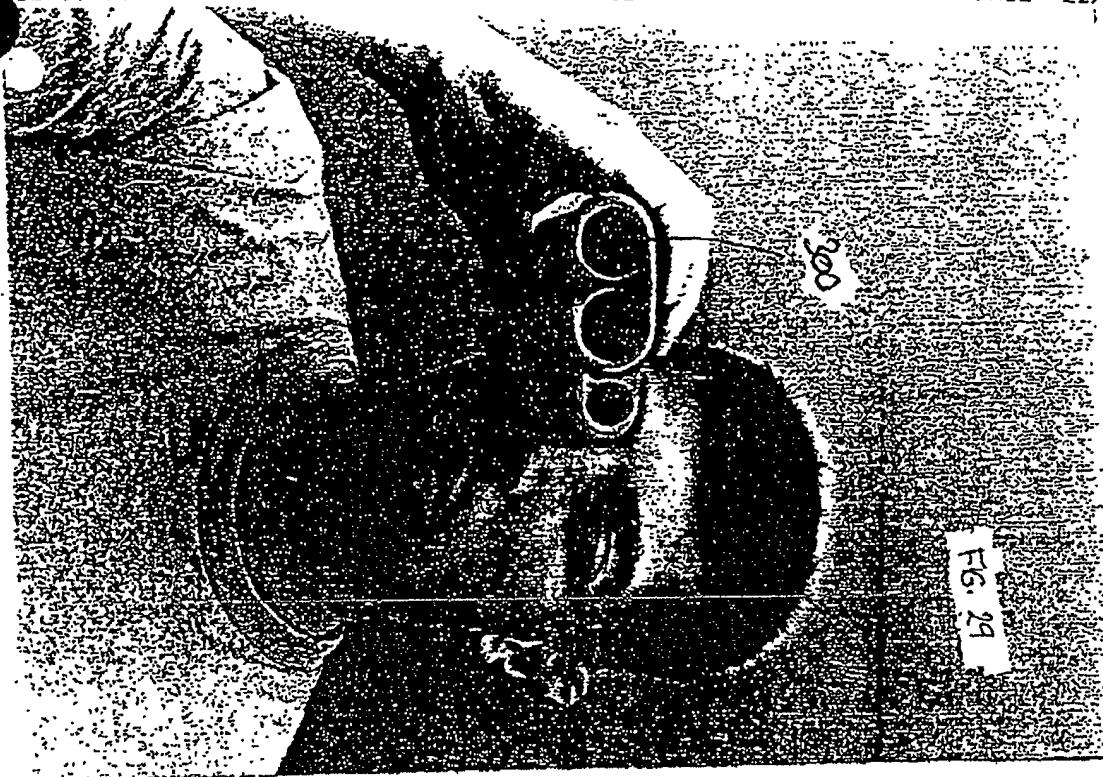


FIG. 30



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